TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

MATERIAL FLOW SIMULATION OF CAR BODY SHOP

Master of Science thesis

Examiner: professor Minna Lanz
Examiner and topic approved by the Faculty Council of the Faculty of Engineering Sciences on 29.11.2017

ABSTRACT

PAULI MYLLYMÄKI: Material flow simulation of car body shop
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The purpose of this Master's Thesis was to examine the material flow of a car contract manufacturer's new body welding process. The company is planning a new body shop for a new car model coming into production. The goal is to evaluate if the new body welding process is sufficient and to find solutions to reach target values.

The research methods used in this Master's Thesis were familiarization with the production system, simulation study, open survey and getting acquainted with process documents. The study also examined previous written literature and articles and researches that were dealing with the subjects covered in this thesis. Research methods used were deemed sufficient to solve the research problems.

The thesis was commenced by getting acquainted with the overall production process. This was done by participating in work activities in the planning phase of the new body shop. The familiarization took part throughout the entire research and with it also open survey was used to gather material for the current state analysis and simulation study.

Simulation study was used to evaluate the new body welding process. Improvement areas were found and this study proposes solutions for these areas. The most important improvement proposal was building another finishing line.

All the proposed options and solutions were evaluated by using simulation study. The results were partly negative but the mostly positive. With the proposed solutions the new body welding process output was on target.

TIIVISTELMÄ

PAULI MYLLYMÄKI: Auton korihitsaamon materiaalivirran simulointi
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Avainsanat: materiaalivirta, simulointi, tuotanto, prosessi, lean

Tämän diplomityön tavoite oli tutkia henkilöautojen sopimusvalmistajan uuden korihitsaamon materiaalivirtoja. Yrityksellä on suunnitteilla uusi korihitsaamo, joka rakennetaan uudelle valmistukseen tulevalle automallille. Tavoitteena oli selvittää uuden korihitsaamon prosessin riittävyys ja etsiä keinoja tavoitteiden saavuttamiseksi.

Tässä diplomityössä käytettyjä tutkimusmenetelmiä olivat tuotantojärjestelmään perehtyminen, simulointitutkimus, avoin haastattelu sekä prosessin dokumentteihin perehtyminen. Tutkimukseen kuului myös kirjallisuuteen ja tutkimuksiin tutustumista, jotka käsittelivät tutkimuksen aiheita. Käytetyt tutkimusmenetelmät todettiin soveltuviksi tutkimusongelman ratkaisemiseksi.

Tutkimus alkoi perehtymällä tuotantojärjestelmään osallistumalla päivittäiseen työntekoon uuden korihitsaamon suunnitteluprojektissa. Tuotantojärjestelmään perehtyminen kesti koko tutkimuksen ajan ja sen ohella käytettiin avointa haastattelua, jonka avulla kerättiin materiaalia nykytila-analyysia ja simulointitutkimusta varten.

Simulointitutkimuksen avulla etsittiin ja löydettiin suunnittelun alla olevasta korihitsaamosta parannuskohteita, joihin työssä esitetään ratkaisuja. Tärkeimpänä parannusehdotuksena esitettiin toisen viimeistelylinjan rakentaminen.

Kaikki työssä esitetyt vaihtoehdot ja ratkaisut arvioitiin simulointitutkimuksen avulla. Tulokset olivat osittain negatiivisia, mutta pääosin positiivisia. Parannusehdotusten avulla uudesta korihitsaamosta saatiin tavoitteellinen määrä tuotteita ulos.

PREFACE

This thesis was made for Valmet Automotive Oy from the need to examine the material flow in a body shop planned for a new car model. This work was carried out as a project engineer trainee at Valmet Automotive's Uusikaupunki site in manufacturing engineering department. I would like to thank Valmet Automotive for giving me the possibility to do my thesis for them and providing me with an interesting topic and interesting workplace. A special thank you goes to my supervisor Timo Karhu for taking me in but also to other employees of the manufacturing engineering department that supported my work.

I would also like to thank Mikko Vehviläinen from Ideal PLM who helped me in program related issues. Without the help the work would have been harder to conduct.

A big thank you goes to my family who has supported me in many ways throughout my years of studying. Especially my girlfriend Villiina who has kicked me forward for years without whom my Master's degree would have possibly be interrupted and who patiently waited for my final graduation. I would also like to thank my co-students throughout my 3 different universities who have made my university studies very joyful.

Uusikaupunki, 20.3.2018

Pauli Myllymäki

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LIST OF SYMBOLS AND ABBREVIATIONS

DES	Discrete Event Simulation
FIFO	First In, First Out
JIT	Just in Time
JpH	Jobs per Hour
JpD	Jobs per Day
KPI	Key Performance Indicator
MTTR	Mean Time to Repair
OEM	Original Equipment Manufacturer
TAM	Finnish, “työaikamalli”
VA	Valmet Automotive
VSM	Value stream mapping

1. INTRODUCTION

The target company manufactures cars for different original equipment manufacturers (OEM). OEM means a company that is the original manufacturer of a product, including planning, manufacturing, inspection and packaging. The target company's products can be seen all over the world. The quality standards are very high and the customer demands include high flexibility. The final customers have hundreds of different options to choose from to build a desired car including assorted colors, accessories and engines. There has been great demand for the current manufactured car models and there is a new car model coming into production in 2018. This thesis focuses on the material flow simulation of the body shop of the new car model.

1.1 Background, limitations and goals

The target company has a new car model coming in to production in 2018. The new car model replaces currently produced model and this change requires alterations in the current car body shop. The new body shop needs to reach certain key performance indicators (KPI) to reach the ordered productions volumes and quality standards. KPI is a measurement that is used to evaluate performance and thus to assess the success of a company. KPI can be a volume produced within a certain time frame or amount of unsatisfactory quality products to name a few examples. These KPI's for the new body shop that were evaluated in this thesis were jobs/hour (JpH), jobs/day (JpD) and availability. The goal of this thesis was simulating car factory's material flow in the new body shop that was being designed and analyze the total process to determine the bottlenecks, buffer sizes and thus determining if the designed process was sufficient.

The subject matter is very extensive and therefore the detailed processes and work stages are not familiarized in detail. This thesis focuses on the overall process of the new body shop and the solutions focus on the overall aspect instead of individual processes.

1.2 Methods

Because the subject matter is very extensive, more than one research method had to be used. Theoretical part consists of qualitative literature review that deals with topic related theory. At the end of the theory part, articles and literature from simulation related experts were gathered and their experiences and knowledge was covered.

In the current state analysis, acquisition of the simulation program and in the evaluation of the production system, empirical, quantitative and qualitative research methods were used. The empirical phase of the study was performed using a simulation study. During the gathering of the material, qualitative methods were used to map the aspects related to simulated production system. These methods were familiarizing with the production system by taking part in the ongoing project and by using open questioning with other employees and departments, and reading produced documents related to the project. The quantitative methods were used to represent the production system numerically to receive comparable results and to explain the techniques used and collected data.

1.3 Material

The material of the thesis consists of written literature, material provided by the target company and material gathered for the simulation study. The theory part is gathered by using the library services of Tampere University of Technology and some of the material has been collected from other written literature that has been available from free to use internet services. The sources of the material have been reviewed to ensure their reliability and accuracy.

For the empirical parts material was gathered from inside the company. Material was gathered by working in collaboration with the company's employees and performing tasks for the current project to map the current state of the production system. Information for the empirical part was gathered from different departments by using open questioning and reading produced documents from the production system to gather vital information regarding separate phases of the production.

1.4 Structure

Chapters 2 and 3 discusses about the theoretical background of the study. Chapter 2 focuses on lean principles, process modeling, layout planning, production planning and management and briefly about the possibilities of production automation and change management. Chapter 3 focuses on the theoretical background of simulation tools and simulation study. Chapter 4 presents the used research methods and material.

Chapters 5,6,7,8 deal with the empirical part of the thesis. Chapter 5 presents the current state of the company and the performed simulation study; how it was done and what were the outcomes of different scenarios. Chapter 6 summarizes the results of the simulation study. Chapters 7 and 8 focuses on the concluding thoughts and conclusions from the simulation study.

2. PRINCIPLES OF PRODUCTION SYSTEM DEVELOPMENT

Competition among manufacturing industries has grown in the past years and will continue to grow in the future. Especially with industry sectors that produce comparable products, the competition is very fierce and consumer decisions can be influenced by tiny things between companies (Koren, 2015). This increases the pressure between companies to manufacture products that are more appealing to the customer. Rao (2011, p.1-4) also points out that manufacturing works as a backbone for nations that have excellent rate of industrialization. Almost 30 % of nation's produced services and goods consist of manufacturing. This means that manufacturing is a great economic asset when considering the living standards of a country and thus the competition may have direct effects in standards of living in some countries.

Technology has advanced greatly in the past years and this has led to a situation where there is constantly new and better technology available. Changing demand put a lot of pressure for the production systems. In the past, it was more about producing one product efficiently but now it is more about options. The manufacturing systems should be built in a way that allows changes in quantities and in the product specifications. The flexibility has become the key in manufacturing system. This means that companies have greater pressure in producing more advanced products faster than the competition but in the end, it comes down to a simple thing, who does it better? (Koren, 2015; Lenz, 2015)

2.1 Lean principles

Lean manufacturing is still considered to be a rather innovative approach in building and shaping production in the world. The ideology behind it is very different when compared to traditional manufacturing systems in mass production. Even if it is considered as a new way of doing things, it has been around for decades. (Hosseini et al, 2015).

Lean is not a physical system that can be implemented in a company and used as a tool. Lean is a philosophy; a way of thinking that will improve manufacturing. It is one way of defining the production system of Toyota. The main idea behind Lean is reducing waste (*Muda*) in different areas of production. There are also three other philosophies that support lean: continuous improvements (*Kaizen*), improving processes and quality (J*idoka*) and Just-in-time (JIT). JIT is explained in detail in chapter 2.1.1 According to Santos et al. (2006, p.1-16), Lean should not be used to pursue short term profits but to constantly improve the organization. There are several different tools that are used to do this. These tools are presented in figure 1.

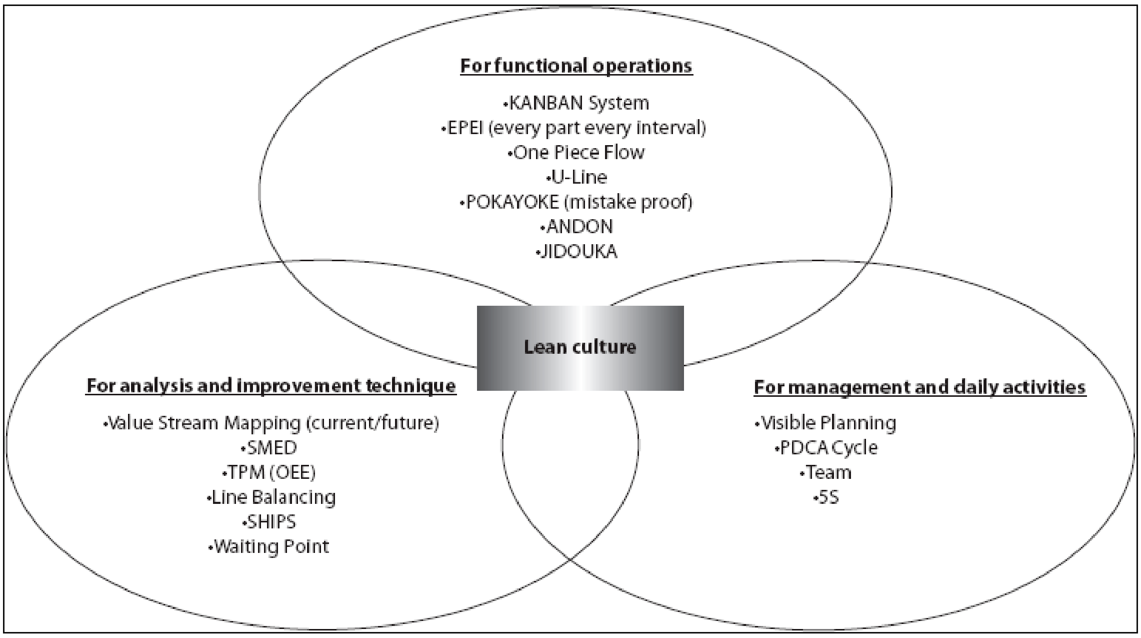


Figure 1. *Lean manufacturing tools (Izumi, 2015).*

2.1.1 Improving system performance with lean

JIT is a production method that is used to reduce waste in different areas. JIT means that only needed products in the right quantities are made exactly when they are needed. In JIT manufacturing companies make just the amount that is needed by the customer so that no extra inventory or waste is created (Hosseini et al, 2015). Figure 2 shows the main principles of JIT and how they are connected.

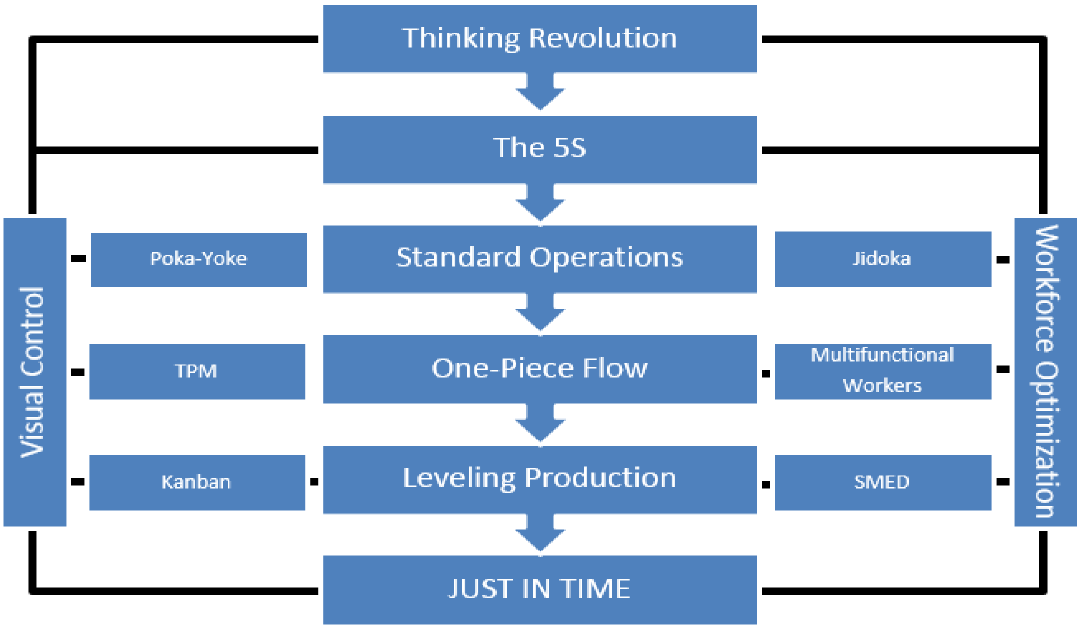


Figure 2. *Principles of JIT (Santos et al., 2006, p.5).*

Kanban is a way of scheduling production. Kanban is very often considered to be the same as JIT (Izumi, 2015) but to be exact it is an approach that supports JIT by making the implementation and control of material processes possible to ensure correct deliveries. Gross & McInnis (2003, p. 1-19) define Kanban as demand scheduling. With Kanban control the production volumes meet the actual demand of products instead of forecasting. This means that a customer will receive a new product to replace consumed product. These new products will be produced based on the signal received from the customer.

Kanban can be considered as an implementation tool. It directs the operations by using the material planning information. It makes JIT possible as it defines what is needed, when and how much. Production can be guided with visual signals such as containers, Kanban cards, markings, colored lights etc. These same visual signals help the production planners and managers to see the production status more clearly thus more resources are made available by reducing the amount of schedule monitoring. These available resources can then be used in other areas such as improving processes or managing anomalies. This also adds more responsibility and control to the value-adding level as process operators have more control (Gross & McInnis, 2003, p. 1-19).

Kanban is a tool that will improve production efficiently if implemented and used correctly. According to Lödding (2013, p. 183-184), it is not actually Kanban itself that will improve the material flow, but the improved conditions of the logistic processes that will cause better realization of results. Some key elements that need to be considered when Kanban is implemented are:

- minimizing amount of variants
- minimizing set sizes
- cell organization to allow one-piece flow
- minimize fluctuation in consumption
- adequate flexibility and capacity inventory
- process containment

Kanban is often used when there are only few variants. It is often combined with a detailed plan for production that is applied across the whole supply chain. Many companies have also moved towards electronically managed Kanban system thus restraining from physical Kanban system (Lödding, 2013, p. 183-184).

Value stream mapping (VSM) is used to outline the relationship between material, entity and information. It is a tool used to reduce waste in the system by focusing in the whole value stream of a product thus improving processes. It presents the information available in process flow diagrams but it also presents information that is needed to plan and satisfy regular customer demands such as inventory, cycle time and transfer modes. VSM requires certain criticism in the evaluation of an organization’s working methods to avoid situations where improvement opportunities are not found (Wilson, 2015).

VSM starts with mapping the present state that shows the relationship between suppliers and customers and the processes that have been selected to be improved. The current information of production and material flow is mapped with the value adding phases and no-value adding phases. Based on this information, a future mapping is made, where potential improvements are mapped with the assumption that the intended improvements can be achieved within a reasonable time. This future map will work as a guide to gain the desired process improvements but with a certain reservation for possible errors because the improvement process is constantly evolving (Izumi 2015; Nash & Poling 2008 p. 1-14).

With VSM the present problems and solutions are easily in a presentable and understandable form and it can be applied in several areas because process and product attributes define the approach on implementing lean production. A simple procedure example is presented in figure 3 (Izumi, 2015). There are different tools for VSM that are used differently and they give different results thus making VSM applicable for several different industrial sectors (Hines & Rich, 1997).

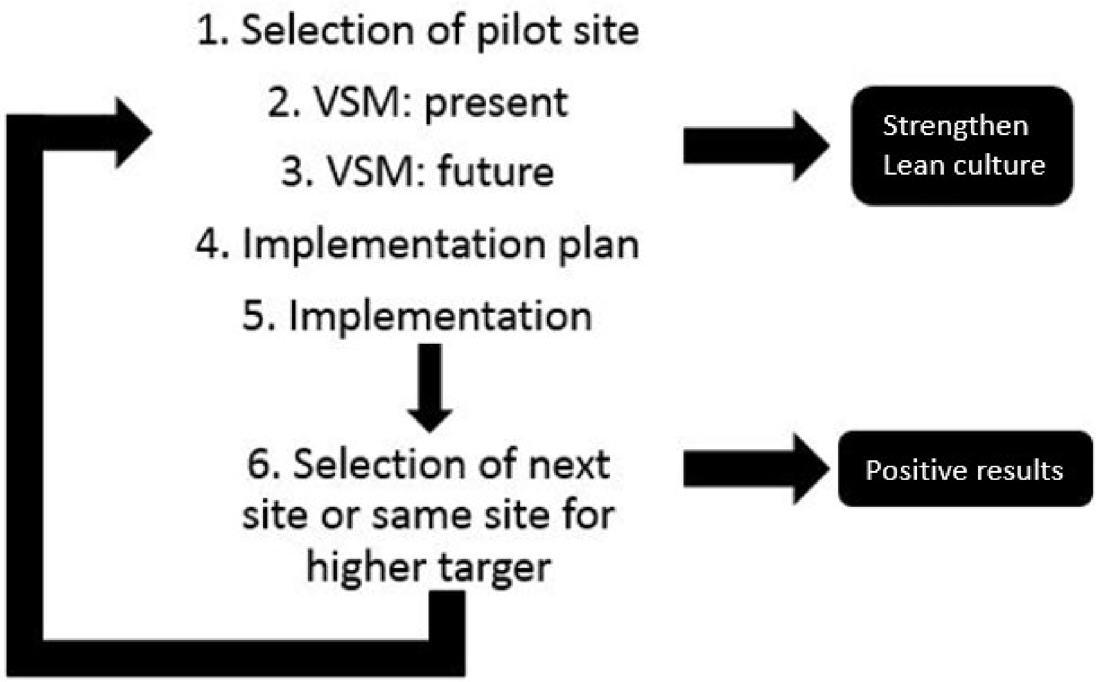


Figure 3. *Lean manufacturing steps (modified from Izumi, 2015).*

Before the actual implementation of the plans, a separate plan for the implementation should be made. This plan should include all the problems that need solving, time frame in which the improvements need to be made, how they are made, who will make them and what is expected. After the planning comes the actual implementation. Implementation requires work and during this phase, lots of alterations will be made in the processes, equipment and connections. The implementation phase may require lots of time and it is the most important phase in lean implementation. If there is no previous experience in lean implementation, simple processes should be selected at first. This will inspire more people to get involved as success is gained more clearly from simple processes (Izumi, 2015). The tools used in the implementation have already been mentioned in chapter 2.1.

2.1.2 Sources of waste

In manufacturing systems, waste is described as an entity that is not needed or can be disposed without having negative effects on the final product. Waste utilizes resources without adding value to the product and thus a company does not gain anything from such actions. Reducing waste has become very important part of production systems as it will increase profitability over time. It is very important to identify several types of waste and their origins to reduce their amount. Wilson (2015) categorizes waste to seven types: transportation, inventory, movement, waiting, excess processing, overproduction and defective parts. There are also sources that describe an eighth type of waste: poor utilization of human resources (Hosseini et al, 2015).

Transportation is among the biggest sources of waste. In manufacturing, it is necessary to move parts and products from one place to another, potentially several times to get the products ready. Some materials may have very costly transportations depending on their nature (dangerous chemicals or heavy parts). This pricey moving is not considered as value adding activity and thus it is considered a waste. Long transport distances also expose the product to several risks that could damage it and longer travel times reduce the actual time in the value adding processes. Unfortunately, transport is something that can’t be just reduced totally; raw material, parts and final products require always some form of transportation. However, it is possible to reduce the times and distances by properly optimizing the routes and ways to deliver. These optimization methods include layout planning to reduce travelled distance and modifying batch sizes. But it is also important to look at the bigger picture; sometimes transport reducing changes in the production might have effects in the total efficiency (Hosseini et al, 2015).

Inventory means having products in store waiting for order from a customer that could be the next process or the final customer. Inventory is a classic type of waste; if it can’t be used directly in sales then it does not support sales. Inventory can be ready products, parts used in manufacturing, work in process or raw material (Wilson, 2015). Inventory is a result of overproduction and it uses floor space, limits communication, results in increased lead times and makes efficiency smaller because a portion of resources is dedicated to inventory regulation. These will then lead to more waste in different areas. In lean manufacturing, inventory is reduced with JIT production. Other ways of inventory reduction are process balancing, outsourcing and flow improvements (Hosseini et al, 2015).

Movement (or motion) can easily be affiliated with transportation, but it is a completely different issue. While transport is more related to bigger scale actions, movement is more related to the ergonomic side of manufacturing; walking, lifting, bending and stretching. Very commonly this is ignored as waste as workers are active because they are in motion and look like they are doing something (Wilson, 2015). Figure 4 shows wasteful movement examples.

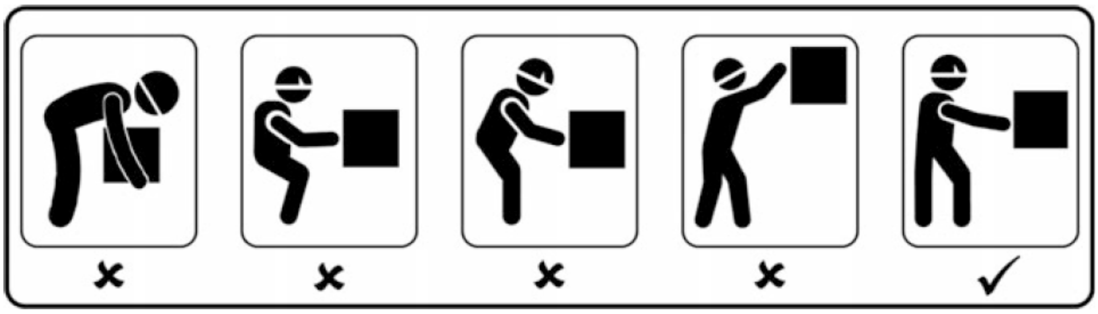


Figure 4. *Examples of wasteful movement (Hosseini et al, 2015, p. 259).*

They key thing in considering movement as waste is looking at the value adding side of it; is the movement necessary to produce a product? Movement that is waste means unnecessary moving such as walking to a tool cart to pick up a tool and move back to a working station or bending over to pick up a part. This wasteful movement causes stress that reduces performance and waste of time and energy thus wasting money. To avoid wasteful movement, working cells should be organized to serve the operator better and jobs should be designed to reduce unnecessary movement; placing tools close by and having them at the right height. Movement also concerns robots and different operations; the more movement, the shorter their life cycle is and longer cycle time (Hosseini et al, 2015).

Waiting is associated with anything when a worker is not working to add value to a product. This happens when a part, material or product is not in motion to be processed. Waiting can be caused by several reasons such as machine failure, bad communication, distance between workstations, bad workflow or lack of raw material (Liker, 2004). Waiting is among the most difficult ones to observe because even if the waiting time would be only seconds, in a big company with several stations and workers with high quantities of products, the waiting could accumulate to a much greater value. Waiting is also among the most common wastes but luckily, it is quite easily corrected by properly identifying the problem areas and managing the workforce to reduce waiting times. The processes should be designed in such a way that the work flow would be synchronized to minimize any time loss (Hosseini et al, 2015).

Excess processing means that a product is processed more than is required by the customer. This includes both engineering or hands on work that is beyond customer needs.

Very common waste in excess processing is in the design phase when unnecessary specifications are included in the product that are not actually needed and is not value adding. Inefficient tools in the processing phase will also create waste due to slowness or inadequate quality (Wilson, 2015). It is very important to define proper specifications for the products as it might not always be clear what is necessary and what is excessive. The customer requirements need to be clear and the process should be designed to be as simple as possible but still meet these requirements. Excess processing can be minimized and removed if the customer, manufacturer and designer communicate to help understand the target use of the product (Hosseini et al, 2015).

Overproduction is considered the "mother of waste" because it is a waste itself but it also provokes the other sources of waste. The overproduced quantities need to be transported, stored in inventory and requires staff that add no value. (Liker, 2004; Izumi, 2016) lists some typical cases that cause overproduction and that are typical beliefs in manufacturing:

- mass production (less cost per product)
- safety stock (storing in case there are changes in demand, or goods are not ready)
- continuous production (better utilization rate despite work-in-progress (WIP))
- production limitations (impossible to produce more than a certain amount)

One commonly used method to solve overproduction is JIT production but also other ways are used that balance the supply chain from the producer to the customer. Overproduction and inventory are directly linked with each other (Hosseini et al, 2015).

Defective parts are among the most detectable wastes. It means wasted material and resources through finished but unacceptable parts. The finished parts could be wrongly sized, poorly finalized or broken. Some parts are fixable and some parts are not possible to be fixed or reused. This leads to material going to waste and direct loss of money or in rework cases, extra resources and material used to fix the part to a desired form without gaining any additional value. In worst cases, defects may lead to losing a customer. To avoid defects, customer needs have to be carefully determined and manufacturing process' quality needs have to be ensured. However, it is equally important to learn from the defects and use them as opportunities to learn and improve (Hosseini et al, 2015; Hines & Rich, 1997).

Poor utilization of human resources is not among the original sources of waste various sources have introduced it as an eighth source of waste (Liker, 2004; Hosseini et al, 2015; Hicks, 2007). It means that people and their skills and ideas to improve processes are not utilized efficiently thus leading resources going to waste. This could mean the potential of running several processes at once or improving cycle time. It is hard to eliminate this waste because it is not a visible waste. Effective communication is needed to identify these employees. Proper training and/or relocation to more proper tasks should be done to reach their true potential.

2.2 Process modeling and development

Process modeling is used to improve operations and productivity. Process modeling is needed when there is need to describe the processes and develop existing processes or create new ones. Process modeling has been a big part of Japanese quality philosophy and in the past years this philosophy has expanded to western industry as well. Process thinking consists of customer orientation, objective orientation, value adding, increasing profitability and system thinking. Process thinking should be a part of implementing strategy in a company and its development. This includes having required tools and IT systems to achieve the set objectives. Process thinking can be applied in all industry sectors whether they are seeking for profit or not. (Martinsuo & Blomqvist, 2010).

Processes should be considered as operations that add value to a customer. Customers can be internal or external, a part of the process chain or the final customer. The next customer will always give requirements to the previous process. A process can be any operation in a company and proper process modeling requires identifying these processes. This makes it possible to measure the productivity through measuring processes (Martinsuo & Blomqvist, 2010). Processes should also be considered as tools in manufacturing. Tools wear out over time and get outdated so they need to be updated, in other words processes need to be developed. Wysocki (2004, p.1-2) summarizes that there is always room for improvement as innovative technologies turn up and better ways of doing things appear. In business world, constant improving is needed to keep the competitive position.

Rao (2011, p.1-4) states that process development is driven by the need to be more profitable. This profit can be achieved through better quality, higher process safety, reduced manufacturing costs and shorter manufacturing times. Processes require capital investment and to get that investment back it is very important that the processes need to be operated as efficiently as possible. It is important to recognize desired state of a process meaning what types of results are expected from a process to achieve certain goals. These goals should be in line with the company’s strategy so that achieving these goals would push the company forward. A big part in this is also recognizing the current state of the process (Wysocki, 2004, p-12-14). Typical process development phases are presented in figure 5.

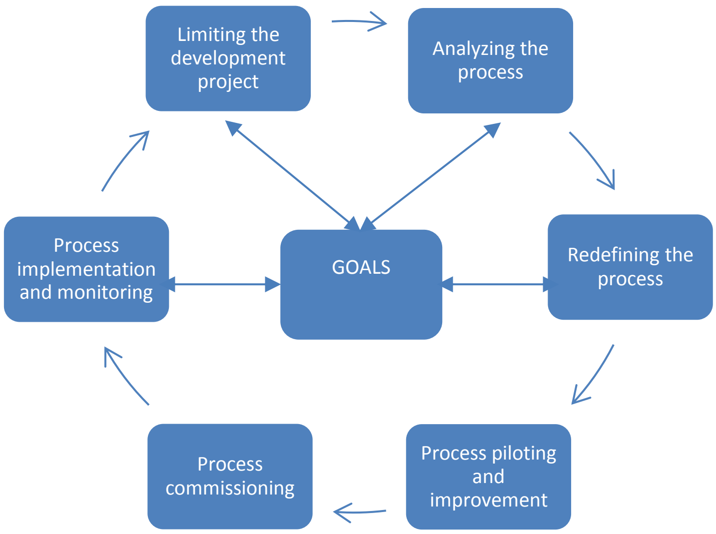


Figure 5. *Phases of a typical process development project. (Martinsuo & Blomqvist, 2010)*

Present process is identifying the current state of the true operational environment and understanding the imperfections in the present state of a process and that the tasks are not ideal. This helps in identifying the development areas. These key areas should be measurable and the most value adding process parts should receive the most attention. These parts should be considered with respect to the goals of the development (Martinsuo & Blomqvist, 2010; Wysocki, 2004 p. 12-14).

Target process is identifying the operational environment of the target process that affect in the profitability goals. The differences between the present and the target processes define the tangible changes. The target process needs to be modeled end-to-end. Through this it is possible to figure out what needs to be changed to meet the customer demands for the specific process. (Martinsuo & Blomqvist, 2010; Wysocki, 2004 p. 14).

Process development is a continuous process. It can be a single project but usually these projects are related and a new project initiates a new improvement project thus making it a constant loop of improvements. (Wysocki, 2004, p.14).

Processes require measuring. These measures answer to questions how much, when, how and so on. They can measure the inputs, outputs and the process itself (Martinsuo & Blomqvist, 2010). These statistics gathered from the operating systems are important in constant development as they will provide concrete evidence on the current state or the end results thus making comparison between these two possible. With decent measurements it is possible to dig in to the true causes of a problem (Sharp & McDermott, 2008, p. 189-190). Table 1 shows some example measurements.

Table 1. *Examples of different process measurements. (Martinsuo & Blomqvist, 2010)*

Input related measurements	Process related measurements	Product related measurements
Resources: workforce, working hours, material costs, capacity input quality (raw material, other material)	cycle time time frame and costs accuracy yield efficiency resource utilization cost utilization payback time amount of anomalies amount of changes amount of new products quality of planning	amount of products value of products quality of products launching time of a product

To start modeling the present process, it is important to have knowledge of the actual processes: equipment specifications, working techniques and possible equations and mathematical applications. Proper optimization techniques are required to have the means to improve. Process efficiency is affected by many distinct factors and changing only one can have profound change in the total outcome. Process mapping is important: value network, critical processes, direct customers, possible added value, links to other processes and the requirements for the process should be clarified to ensure efficient working environment (Rao, 2011, p.1-4).

Processes need to be described coarsely first. This means recognizing the material flow with starting and ending points and identifying the limitations for the processes. The steps of a process and what happens in every step needs to be clarified. After this comes the detailed descriptions: what are the most critical processes? What are their tasks, how are they interconnected, what are their roles and responsibilities? What equipment is used and what information is needed and what information they produce? If there are a lot of uncertainties in a process, then it should not be observed in too much detail as this may results in developing the wrong areas (Martinsuo & Blomqvist, 2010).

A process model should be clearly and simply described. It needs to focus on the essentials and keep the information flow separate to avoid misinterpretation. Process branches should be clearly separated. It is important to have all the correct stakeholders involved in process modeling to assure the correctness of the model. This helps in the future when the key points to be developed are defined (Martinsuo & Blomqvist, 2010).

2.3 Layout planning

Layout planning means planning of departments and machinery with their locations and defining workstations and material flow in a production system (Jääskeläinen, 2017). According to Santos et al. (2006, p.18), layout has direct impact in a company's throughput and lead time. Layout is an issue that every developing company needs to consider. Layout needs to be carefully considered every time there are changes in equipment, processes or products.

Layout planning promotes manufacturing processes but will also help in achieving several different objectives, such as material handling minimization, floor space optimization, maintaining product flow and increasing employee safety and satisfaction to name a few. Despite the products and processes, these objectives do not vary between industry sectors that much. Restaurants and factories will all need layout planning to solve different issues whether they are building a new site or developing a current one (Muther, 1968).

2.3.1 Planning process

Muther (1968) summarizes that without proper layout planning, factory rearrangements will cause loss of time and resources and will result in inefficient use of the plant. Santos et al. (2006, p.19-20) points out that there are several reasons why a company must perform a layout change. These most common reasons are:

- Location change
- New equipment
- Material flow problems
- High WIP

In layout planning, there are two aspects that define the nature of the layout plan: product and quantity. Product defines the raw materials needed and different options. Quantity defines the amount that needs to be produced (tons, pcs etc.) These elements will define the course of the layout plan as the plan should essentially achieve something. The information about the elements should be gathered and the layout should be planned to accomplish the desired outcome (Muther, 1968).

According to Schenk (2010, p. 18-19), a planning project can be executed in two ways: systematically or event based. Systematic planning process follows a determined process from the beginning to the end. The phases in the process can be repeated when necessary. In event based planning the process is related to the operative decisions. The decisions on the targets, data, product, technologies, productivity etc. affect directly to the planning process changing it entirely or partially.

While Schenkin's (2010, p. 18-19) planning process can be used throughout a facility's life cycle, Santos et al. (2006, p. 30-33) lists 6 steps that are more specific in layout planning. These 6 steps are shown in table 2**.**

Table 2. *Steps in layout planning (Santos et al., 2006, p. 30-33).*

	Step	Definition
1	Formulate the problem	Defining the main objective of the study
2	Analysis of the problem	What is the current situation now
3	Search for alternatives	Defining the problem and finding different solutions through proper analysis, such as considering the big picture, most ideal solution and then the practical one and brainstorming
4	Choose the right solution	The alternatives in step 3 should be evaluated and ranked based on what suits the best.
5	Specification of the solution	The solution should be developed in detail before implementing it. This includes costs, schedules etc.
6	Design cycle	The implementation of the solution may cause issues. Costs may vary and other problems may arise. It is important to plan and coordinate these problems as well.

2.3.2 Different layout options

According to Santos et al. (2006, p.25) four diverse types of layouts can be examined:

- Fixed-position layout
- Process layout
- Product layout
- Cellular or combination layout

According to Hu & Ko (2015) a factory's production can be a configuration of different layouts that may vary based on the product, quantities and equipment. For example, a product's sub assembly may have different layout than the actual assembly line.

Fixed-position layout

Fixed-position layout means that the resources required to produce a product are moved to the product and the product itself does not flow through the production (Santos et al., 2006, p.25-26). Figure 6 illustrates the structure of a fixed-position layout.

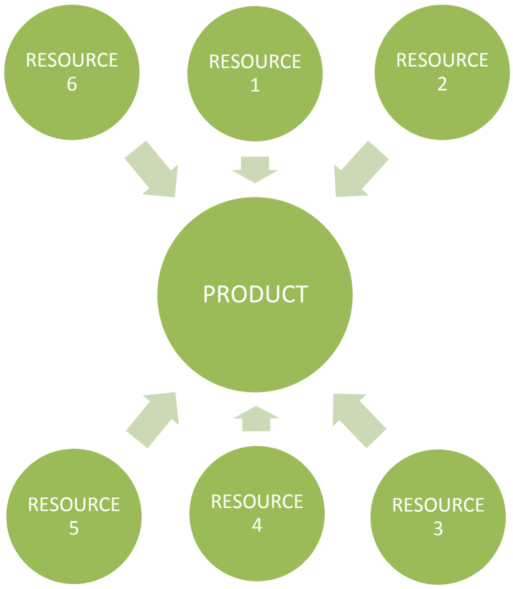


Figure 6. *Fixed-position layout.*

These types of products include ships, building construction or other products that have very small production volume, often equal to one (Bidanda & Needy, 2001, p. 14.151) or other products that are difficult to move (Santos et al., 2006, p.25-26). Before being modernized to its present form, automotive industry started with fixed-position layout.

Process layout

In process layout, similar resources are divided into departments based on their activities (Santos et al., 2006, p.26-27). For example, welding equipment is grouped in the welding department and millings form the milling department. The material flows from one department to another in a product specific sequence. This means that all products do not flow through the same stations as the products may have different requirements. Process layout is mostly used in a job shop type of manufacturing where only small quantities of products are made due to specific requirements of orders (Bidanda & Needy, 2001, p.14.149-14.150). According to Santos et al. (2006, p.26-27), this type of layout has good flexibility but the downside is poor management of jobs, long setup times and material handling, big amount of inventory and low automation. Illustration of process layout is presented in figure 7**.**

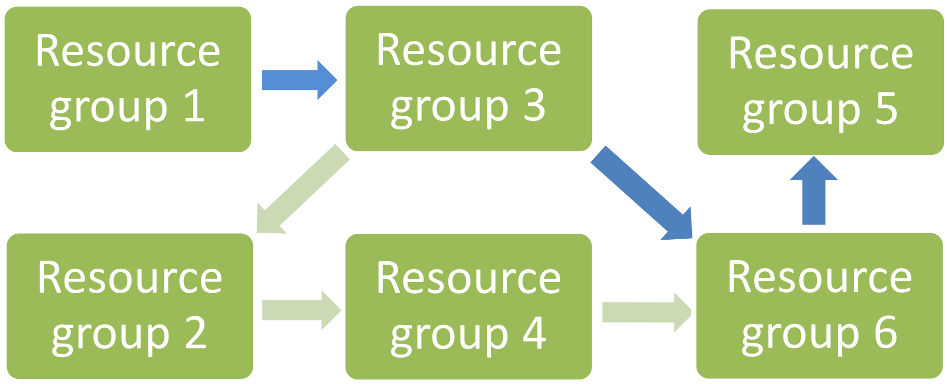


Figure 7. *Process layout (distinct colors indicate different paths per product).*

Product layout

In this type of layout, the resources are arranged according the sequence the product requires. Product layout is used to produce high volumes of distinctive products (Bidanda & Needy, 2001, p. 14.149). Figure 8 illustrates the product layout.

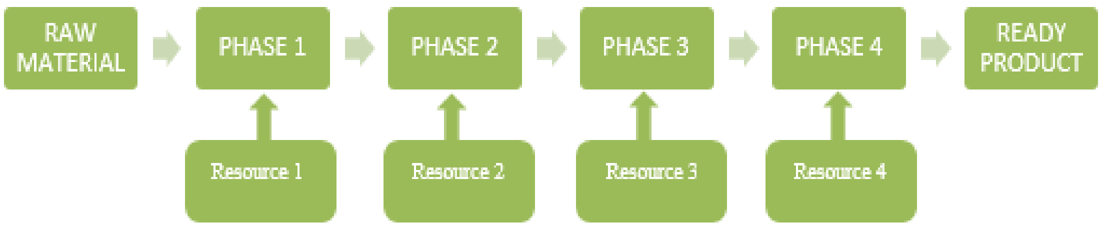


Figure 8. *Product layout.*

Product layout is also called an assembly or a manufacturing line. Product layout is an effective way of producing significant quantities of products with minimal material handling. The production is easily managed and the level of automation can be high as the processes perform same tasks continuously. The downside is the poor flexibility and high setup time for the system (Santos et al., 2006, p. 27-28).

Cellular or Combination layout

Cellular layout is where production is divided into cells. These cells include the necessary operations required to produce a certain product. This way several assorted products can be efficiently produced as different product flow through different cells. The operations in the cells are typically organized into a U-shape and the operators are typically trained to operate several different machines (Bidanda & Needy, 2001, p. 14.151). Figure 9 presents an example of a of cellular layout.

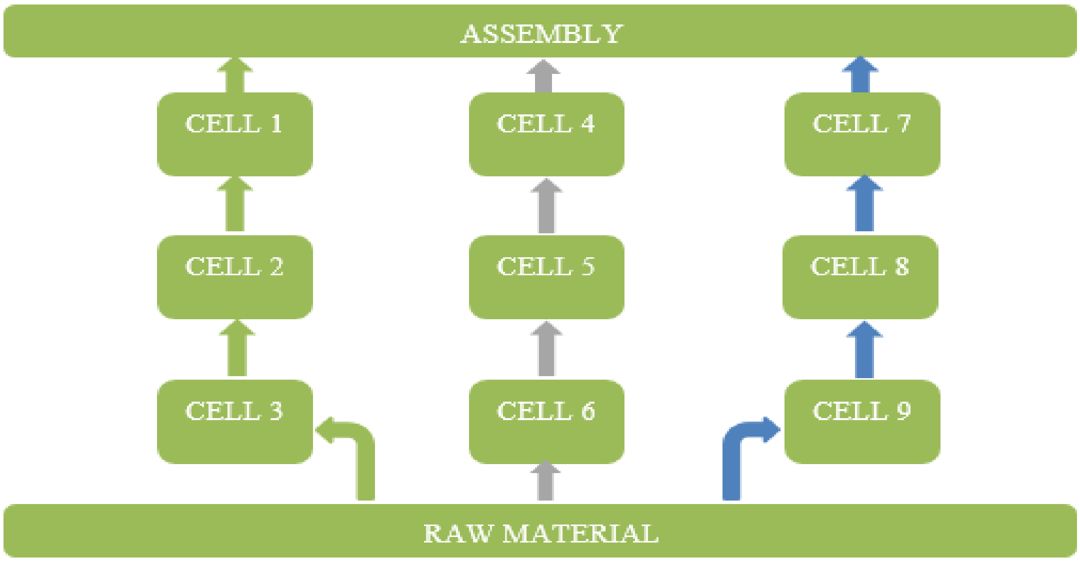


Figure 9. *Example of a cellular layout.*

Bidanda & Needy (2001, p. 14.151) state that cellular layout is formed of cells that have similar attributes, meaning that part that are produced in a cell are being processes with similar equipment or labor or other resources. Bidanda & Needy (2001, p. 14.151) emphasize that the most important thing in cellular layout is the formation of these cells to have efficient production flow. Santos et al. (2006, p.28-29) state that companies producing large products such as airplanes have moved towards modularization. This means that the product itself consists of different modules and these modules are manufactured in several types of lines and final modules are then assembled.

According to Santos et al. (2006, p.28-29), some companies lack the possibility of cellular layout due to excessive costs coming from necessary purchases. To avoid excessive costs, the layout can be rearranged to share the key resources. This is known as combination layout. Combination layout uses characteristics from process and product layout. High volumes of products that require special processes can be produced with the efficiency of a manufacturing line. Illustration of combination layout is presented in figure 10.

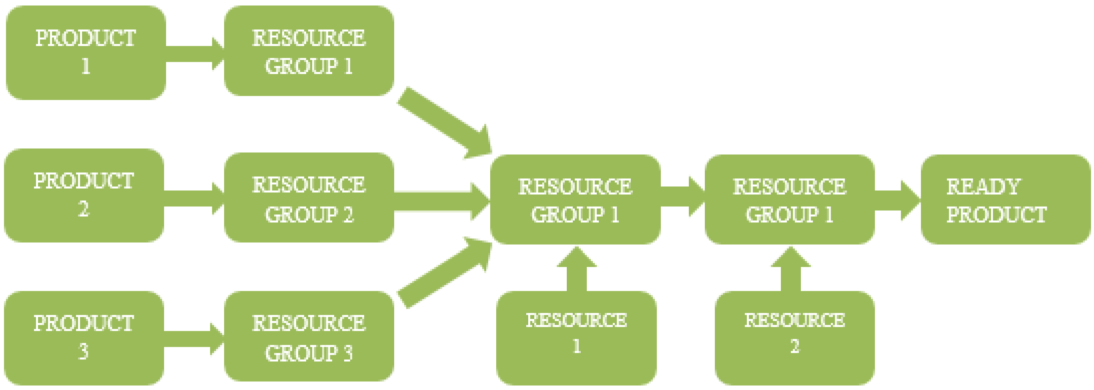


Figure 10. *Combination layout*

2.4 Production planning and management

Lödding (2013, p.85) characterizes production planning as planning the incoming and outgoing work in production and their work order. Production management is then responsible for executing this plan and controlling it so that the desired outcome is reached.

2.4.1 Production planning

Production planning includes the following tasks: production program planning, production requirements planning and planning the jobs done in-house and by external suppliers. The actual production program defines how much of products are produced and when. With this information, the total requirements of the production activities are determined. The production planning is triggered by a sales plan which includes the needed quantities and their required timeframes. The sales plan includes also more details of the ordered options for the products and projected future sales. It also includes the sales on spare parts and special needs for products such as prototypes. Anything that has requirements for production should be listed to achieve an accurate plan for production (Lödding, 2013, p. 86; Halevi, 2001, p.4).

After the production program is done, the production requirement planners need to acquire the amount of resources and material needs from the program. This is done by first determining the needed components; in other words, how many parts every product needs. Manufacturing orders are then created based on the actual needs. This amount is calculated from the difference between needed quantities and stock. Manufacturing orders are then scheduled so that the parts needed for the product are manufactured before the product comes into manufacturing. When the parts are ordered and their delivery dates are known, it is then possible to schedule the production. In many industries and companies, the material requirements are determined with computer software. To optimize production, it is important to plan the requirements so that unnecessary downtime is avoided and capacity can be increased. This is done by planning consecutive production times with economical lot sizes (Lödding, 2013, p. 88; Halevi, 2001, p.4).

Both in-house and externally made jobs require lot size calculation. Lot size calculation for in-house jobs are usually driven by costs. The general aim is to minimize the costs by calculating a lot size that would minimize the setup time but also minimizes the inventory. Setup costs occur every time a workstation is stopped and reset with new setting (e.g. different variant of a product). The costs come from materials, personnel and lack of productive time. The increase of lot size will decrease the setup costs. On the other hand, high lot sizes increase inventory that increases capital tied to products that increases storage costs. The lot size calculation is used to minimize the total costs for these two (Lödding, 2013, p. 92). In externally manufactured parts the lot size calculation has different drivers and cost factors. The factors that influence the calculation are delivery time, transportation costs, how often the deliveries occur and inventory costs (Lödding, 2013, p. 113-135).

The exact times when a product is made can be defined with finite scheduling and sequencing. With it, it is possible to determine the exact times when certain resources are needed. According to Lödding (2013, p. 94), finite scheduling is highly criticized. The detailed starting and finishing dates are planned by the minute which usually leads to delays. If a company manages its operations sufficiently, it can reach its targets also without finite scheduling. On the other hand, with finite scheduling it is possible to see that in theory it is possible to implement certain plans for orders. There are different tools used in finite scheduling. They present the information visually that helps to understand the state of the production. There are also certain algorithms that help in sequencing by prioritizing e.g. earliest delivery date Lödding (2013, p. 94-95).

2.4.2 Production management

The complexity of today's products, their tailoring options and faster production times cause production systems to be more complex. This complexity causes pressure and challenges to production management due to more increased demand on flexibility and efficiency while maintaining low costs. Poorly managed production will lead to elevated level of WIP which binds capital, leads to poor reliability of delivery and weakens productivity (Karrer, 2012, p. 1-2).

According to Lödding (2013, p. 140-143) there are two ways to generate orders: make-to-order and make-to-stock. In make-to-order the order coming from a customer is the trigger for manufacturing order. In make-to-stock production the direct link between customer orders and manufacturing orders is absent and the actual trigger comes from the stock and the customer order is then delivered from the ready stock.

In make-to-order management style an order comes from a customer and this creates a production order that is designed to satisfy that customer's need. Make-to-order is usually used when the products are tailorable for a customer's specific needs. There are companies that use customer neutral products to maintain continuous production and to minimize the setup times. In make-to-order there should be products that does not bind capital to a large storage thus making the production less risky. A customer order can also be cut into smaller production orders if the order has a large volume. Many smaller customer orders can also be combined to form a bigger production order if each of the customer orders are small or separately they would cause large set up costs (Lödding, 2013, p. 140-142). According to Kreipl and al. (2006) make-to-order management style is more prone to having lot sizes that are exactly as demanded.

In make-to-stock the production order is generated before the actual customer order. The customer orders are delivered from a storage that has ready products. This means that the products are not so specifically designed to satisfy the exact need of a customer. In make-to-stock the trigger for creating a production order can be a reduction in the quantities in the storage or reserving already made products. Positive attributes of make-to-stock manufacturing are quick delivery times and flexibility in unexpected situation such as broken equipment, when a stop in production would not cause delays in deliveries. On the bad side, it requires large storage capacity that binds capital. Make-to-stock products are usually more generic products that can be produced constantly (Lödding, 2013, p. 142-143).

There are two ways to generate a production order: single level method and multi-level method. Single level production order creates a production order for just one part number or product. Single level production order can't be used to create separate orders for the components that are needed to manufacture a specific part number. This leads to slowness in information flow and may affect in late deliveries of these needed components. On the other hand, it is possible to handle bigger entities if a product has a specified structure of components and sub-parts thus making is possible to create production order for these as well. In multi-level production order, all the part number's components and sub-parts receive their own production order. The information from the customer order flows quickly through the process and results in efficient production. On the downside, multi-level production orders require lots of information processing. It is more complicated to execute because it creates a separate production order for each component that the product needs. The total amount of these products should be considered in the production orders with different sub-assemblies. This way the scheduling of the production is correct and assembly timing is efficient (Lödding, 2013, p. 143-146).

Production orders can be created regularly based on a specific time span or based on specific events. Usually the time span used on regular orders is the beginning of a period, such as beginning of a week or a month. The downside of time based order is the poor ability to make changes in the production orders during a period; the changes will not be implemented until the beginning of the next period when the next production orders has not been done yet. In an event based production order the order creation happens from customer order, low level of material in storage or other events. This type of order creation requires lots of information processing inside the company. There are several ways to control the event based order creation. Some common ones include Kanban, CORMA, order point system and synchro MRP (Lödding, 2013, p. 147-148).

2.5 Automation in manufacturing

Competition in the present world has become fiercer and requires more efficient supply-chain system from suppliers. The pressure to be more cost-effective in labor costs and to improve delivery time with less damage caused to products has driven companies to invest in automation in material handling. With increased automation, better throughput and integration between warehousing and production is pursued to remain in the market (Chung & Tanchoco, 2009).

Most of the automation in present production systems are related to material handling. The automation of material handling supports lean by shortening time consumed in moving material from one place to another and reducing quality errors caused by material transportation. It also helps to track manufacturing in more detail (Chung & Tanchoco, 2009).

There are several different options for material handling inside a factory. Groover (2008, p. 282-283) lists five categories based on the type of equipment used:

a. Industrial trucks
b. Automated Guided Vehicles (AGV)
c. Monorails and other rail guided vehicles
d. Conveyors
e. Cranes and hoists

Industrial trucks are divided into two categories, powered and non-powered. Powered ones are controlled by humans and are designed to move materials with industrialized movement. Non-powered are simple carriers with wheels that are moved by human labor by pushing or pulling (Groover, 2008, p.282).

AGVs are vehicles that move autonomously. They are usually equipped with batteries or other energy source. They follow a path that has been defined specifically for each material that requires movement. AGVs are usually integrated with other equipment that are automated, e.g. cranes that lift the material off the AGV after it has reached its destination (Groover, 2008, p.282-283).

Rail guided vehicles move along a specific rail system that is suspended from the ceiling or is built on the floor. They are independently operated and by building a network of rails, they too can deliver different material to different stations. Rail guided vehicles are usually driven with electric motors and they take their electricity directly from an electrified rail (Groover, 2008, p.283).

There are lots of different conveyor types for different material types. Conveyors move along fixed paths and are designed to carry significant quantities of material. They can be powered but there are also non-powered conveyors that are utilized by manpower or by gravity. The source of the power is built into the fixed line meaning that the conveying platform moves. These platforms can be belts, chains, rollers etc. (Groover, 2008, p.283).

Cranes and hoists are used to lift objects. They can also move material from one place to another but they cannot be used as efficiently as other material handling systems. Cranes and hoists can be manually used but there are also automated versions. Hoists are usually attached to cranes which provides the option of moving material both horizontally and vertically (Groover, 2008, p.283).

The purpose of having an automated warehousing is to minimize the time spent in processing material, improving the usage of space in the factory storage areas, reducing labor costs etc. Even if the whole production would work as planned, some storage is still needed. Even if the final products are delivered directly after they are produced, they still need to go through some temporary storage during their production life cycle and part of material used in production has to be stored at some point. Despite the time the material or the final products are being stored, proper consideration needs to be given for the methods of storing these materials. There is vast variety of different automated storage options available for different material types (Groover, 2008, p. 283).

2.6 Change management

With increasing complexity and amount of changes in present day industry, change management has risen to become a critical topic in organizations. Modern technologies, globalization and better ways of doing emerge constantly and managing these changes effectively is considered as measurement of success in the constantly changing world (Anderson, 2010).

According to Luomala (2008, p.4), the signal for a change needs to come from within the company itself. Change cannot be forced and change should not be pursued if there is no need or competence to complete a change properly. Kotter (1995) lists 8 steps that should be followed to achieve rewarding change:

1. Establishing a sense of urgency
2. Forming a powerful guiding coalition
3. Creating a vision
4. Communicating the vision
5. Empowering others to act on the vision

6. Planning for and creating short-term wins
7. Consolidating improvements and producing still more change
8. Institutionalizing innovative approaches

According to Luomala (2008, p.4-9), efficient change management requires not only considering the change itself but also considering the people involved in the change, e.g. how does a physical change in the process affect the operator? Despite the circumstances, in every personnel organization, a successful change management requires considering all stakeholders and connections.

Good implementation of change requires proper planning that includes the goals of the change, relevant actions, people involved and schedule. The key players in successful change management are people, resources and evaluation. It is very important that the management has committed to the change project. It is also very important to find the key persons in an organization that are highly involved already in the planning phase and not only in the execution phase of the change. Resources should be sufficient and versatile and enough time needs to be reserved for the whole change process. The plan should also include possible setback and pitfalls, because with every change lies a risk of failure but also chance of success (Luomala, 2008, p. 4-9).

No matter the change, there will always be resistance and challenges. Smaller resistance focuses more on questioning the positive results and outcome. In every change, there will be at least some amount of smaller resistance and it is usually over in a brief time. Stronger resistance will endure longer and has more significant negative effects on work motivation and on the desired outcome These issues should be considered already in the planning phase (Luomala, 2008, p. 4-9).

3. SIMULATION AS A TOOL IN MANUFACTURING ENGINEERING

3.1 What is simulation

Banks (2004, p. 3) defines simulation as duplicating real-life mechanisms under a certain period. According to him, part of simulation is having an accurate and history based simulation model that is compared with the real-life system.

According to Ng, Jie and Kamaruddin (2014), there are two distinct types of simulations: discrete event simulation (DES) and continuous simulation. In DES, the simulation model consists of separate events and simulates the real world based on these events. For example, a truck arriving to a loading dock is an event and it leaving is another event. The loading time is considered as a delay between these events. Continuous simulation is based on activities and includes regular progressive system tracking. In continuous simulation, the variables change constantly, for example, simulating movement of liquid. Continuous simulation is better in systems that have constantly changing irregularities. DES is better when the systems are more complex because through it, it is possible to try out several possible changes in the system.

Industrial systems and their actions are studied with simulation models. In theory, the model is an artificial version of the actual operating system. In these simulation models the assumptions are fabricated with mathematical, rational and typical solutions that are communicating with the desired operations, units and objects of interest. When the model has been constructed, it is important to verify and validate it. This happens by performing the simulation study with given values and analyzing it with the actual history of the operating system. The results from the simulation model and the physical system should provide equivalent results. This way the model will provide as accurate results as possible in the upcoming simulations (Banks, 2004, p. 1-8).

According to Carson (2015), a good simulation model is a tool that will help to make decisions. Simulations are used to classify and analyze the design of original industrial systems but also to evaluate the modifications in previously used systems or in the development phase of an entirely new system. Banks (2004, p.1-8) states that simulation is a tempting tool because it imitates the events of the real-life system and it can be used to demonstrate a system that is still designed.

3.2 Process simulation steps

According to Banks (2004, p. 12-16), there are certain steps that need to be considered in building a solid simulation model. There are differences in the steps and methods, but in general the steps have the same frame that should be followed. According to Carson (2015), a simulation study is divided into four sections: project initiation, project work, model verification and validation; and experimentation and analysis. Banks' example of the steps in a simulation study are shown in figure 11**.**

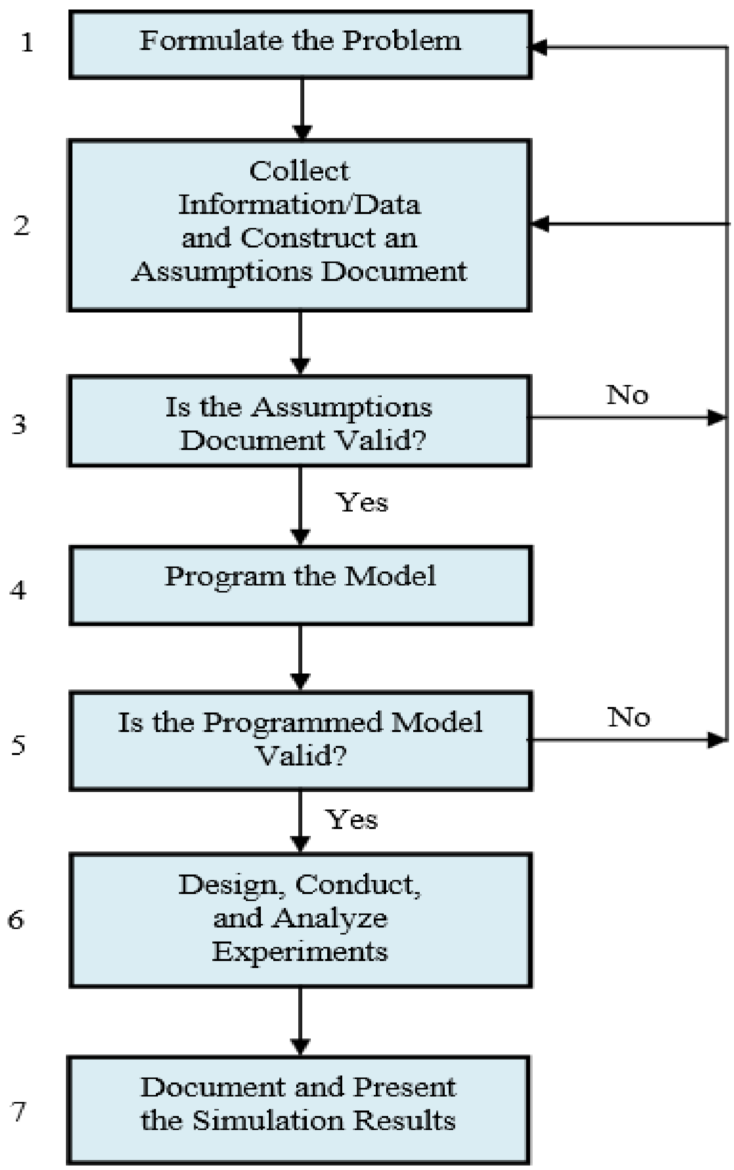


Figure 11. *Steps in a simulation study. (Law 2009)*

3.2.1 Project initiation

Problem formulation and setting objectives is the first step in a simulation project. The problem should be clearly stated and the simulation model should serve the objectives. Sometimes it can be hard to determine the actual problem or the objectives clearly, but it is important to have an idea on what needs to be improved (for example, buffers are too high). It is important that all the parties that are affected by the project and are interested in the outcome are also present at the initiation and present the problems and questions they need answers to. They should also be involved throughout the whole simulation project (Carson, 2015).

According to Law (2009), in the beginning of the project, there should be a kickoff meeting that includes the project management, simulation experts and other case-related experts. The kickoff meeting should clarify the following issues:

- comprehensive objectives and detailed questions that need answers
- measurements that are used to assess the work
- different configurations for the modeled system
- scope of the simulation
- usable resources and time span

Overall project plan should be made by the simulation expert after all the information is received and correct. The project plan should include estimations from overall time span and time required for the model creation, validation, verification and experimentation. Based on this information and cost evaluation, the management will decide if the simulation project will go on as planned or are there some changes in the scope (Carson, 2015).

Conceptual model and assumptions documentation is essential and even critical to avoid iteration and to have a reliable outcome. According to Carson (2015), the assumptions documentation includes the hypothesis that have been agreed upon and it has the requirements for the information. It should be clearly written so that all interested parties understand it and agree upon the facts. It is important to have all the information in written form with also the problem formulation and objectives, because the purpose of the documentation is to work as a communication tool with all the interested members. The assumptions document with the agreed-upon information also works as the conceptual model. Banks (2004, p. 12-16) points out that when the simulation model is being built, it should follow the assumptions document and agreed data so that the model would not exceed the needed complexity.

3.2.2 Project work

Model development is the actual start of the simulation model building. According to Carson (2015), the development is divided into two sections: (a) constructing the data into form that shows the relations between objects and data and (b) converting the data from the assumptions document into a form that can be utilized in the simulation model.

Data collection, cleansing and analysis might turn out to be quite laborious part of the simulation study. The data is usually gathered by the client that has ordered the work or if there is no specific information available, they provide estimates. In some cases, it is possible that the simulation analyst will gather the data and estimations through databases, previous studies and collection systems. It is very important that in cases like this, the collected data is verified with the client (Carson, 2015).

When the data is collected, it is not often in a required form or lacks the needed quality and needs cleaning. Databases and systems may have significant quantities of data but sometimes only a small portion of it is needed. There may also be inaccuracies in the data and man-made labor versus computer-made labor might have great differences even if the work itself would be similar (Carson, 2015).

3.2.3 Verification and validation

Carson (2015) states that this is the last phase of the model building. At this point all the data is collected and the simulation analyst will verify and validate the model so that it is ready for the actual simulation study. At this point, all the errors and faulty data can be corrected with the client. The point of verification and validation is to reduce the disbelief among the simulation model and the results it produces. Banks (2004, p. 12-16) also points out that the point of verification and validation is not the last phase to be conducted when the model is finished, but an essential part of the continuous model development.

Model verification means that the simulation analyst will go through the simulation model and make sure the model is correct. This is done by running the simulation model repeatedly in several ways to make sure the simulation model works according to the assumptions document. So, in short, the point of verification is to make sure the model works correctly (Banks, 2004, p. 12-16)

Model Validation is very important part of simulation model building, because it determines if the simulation model is correct and if it describes the actual working system. According to Banks (2004, p.12-16) the validation may require iteration as there might be lots of inconsistencies that should be discussed with the client. This phase may need lots of repetition to achieve an acceptable simulation model. Carson (2015) also points out that this is the phase where the client is involved and where all the members that are interested or have contribution in the model, are included in the validation.

3.2.4 Experimentation and analysis

Experimental design is the phase just before the experimentation. In the design phase, the simulation analyst needs to determine the specifications for the experimentation. These specifications include the parameters, simulation run length, warm-up period and how many times the model will be run. Different combinations of these should also be considered. Run length is usually determined by the nature of the system. The complexity of the system usually dictates the amount of repetitions; more variable systems need more repetitions. It is important to understand that there are no specific rules for these specifications. They should all be based on the specific experiment and thus the same specifications will not work as a universal rule (Carson, 2015).

Experimentation is the part where the simulation model is in use and the actual simulation study begins. In the project initiation, the goals and objectives were clarified and based on these, the simulation analyst will simulate different scenarios. According to Carson (2015), usually simulation models are utilized to analyze the differences between different possibilities (e.g. two different plant system layouts). In some cases, the first experimentation will send the following experimentation into another direction than first planned. This could happen if there are results received from the first experimentation that reveal system vulnerabilities or failures that would also appear in the following experimentation. Therefore, experimental design should be performed before each step in the actual experimentation.

Analysis phase is where the results of the simulation study are analyzed based on the objectives and problems stated in the beginning of the project. Some of the typical measurements in manufacturing systems are total production volume, buffers, resource usage and lead time. To identify the problem and to produce reliable proposals for improving the system design, the actual model may need several simulations, because sometime the first simulations are not sufficient to locate or identify the problem cause or nature (Carson, 2015).

Reporting is the last phase of a simulation study. The reporting should include at least a written report and a presentation. According to Carson (2015) and Law (2009), the final report should include the assumption document. According to Banks (2004, p. 12-16), the final reporting should also include a detailed description of the simulation model to allow future simulation studies with the same model. It is also advisable to use constant reporting rather than one definitive deadline to keep the client informed always, to reduce confusion among project participants and to keep a log of the decisions made throughout the project.

3.3 Simulation in manufacturing systems

Simulation can be an efficient tool in manufacturing systems. Simulation has been used already since the 1950s to find answers for different business issues to increase profitability and efficiency. It is a tool for all industries including services and manufacturing. As simulation means mimicking reality, it can be applied virtually anywhere. Good examples of simulations are flight simulators where pilots can mimic real life situations and train for various kinds of situations before piloting an actual plane (Heilala, 1999, p.3).

According to Hwaiyu (2016), simulation is not a tool that provides solutions, but a tool that is used to assess. It does not provide answers to question "how it should be" nor does it replace the work of an operator. It provides us an expansion for our own thoughts and helps us understand system complexity. According to Heilala (1999, p.15) there are two fields where simulation can be used: system development and operational controls.

Simulation can be used as a tool when designing a new system or when an old system is being developed. Manufacturing systems include both automation and manual labor and numerous different variables might affect the processes. Different cycle times between stations and various products affect the material flow. Simulation can provide help in analyzing the processes and find potential solutions for material flow issues, such as bottlenecks (Heilala, 1999, p.3-4).

Operational use includes working with the current system and optimizing it and running different scenarios etc. It can be used to support operational decisions. Simulations also provide valuable information from the production system when customer orders are concerned. Simulation can improve the reliability of deliveries and provide answers to production management related questions such as shorter throughput that would result in faster deliveries (Heilala, 1999, p.13-14).

Banks (2004, p. 425-426) emphasizes on the importance of understanding the concept of simulation and that the scope of simulation studies should be regulated by the objectives of the project. This means that the level of detail should be assessed by the questions that require answers or by the availability of data. This limits the objects and parameters in the simulation model; all unnecessary information should be ruled out. Table 3 shows some typical parameters used in a simulation model of manufacturing systems.

***Table 3.** Typical components in a manufacturing system. (Banks, 2004. p. 426-427)*

Manufacturing system parameters	
Physical layout	**Labor** Time schedules Tasks and certification
Equipment Rates and capacities Malfunctions Mean-time-to-failure Mean-time-to-recover Resources needed for repair	**Maintenance** PM schedule Required time and resources Tooling & fixtures
Work centers Processing Assembly Disassembly	**Product** Product flow, routing, needed re-sources Bill of material
Production schedules Make-to-stock Make-to-order Customer orders Line items and quantities	**Production control** Job assignments Job selections Routing
Supplies Ordering Receipt and storage Delivery to work centers	**Storage** Suppliers Spare parts WIP Finished output
Packing and shipping Order consolidation Paperwork Loading of carriers	

3.3.1 Data collection

Banks (2004, p. 426-430) describes data collection as one of the most laborious parts in problem solving. Data collection is among the most important problems in simulations. Basic computer science term "garbage-in, garbage-out" can be applied in simulation studies. If the model is correct but the data is incorrect, the output of the experiment will be inaccurate. Depending on the simulation study, there might be many different areas from which data needs to be gathered to have enough information about the manufacturing system and to build a reliable model. Bangsow (2015, p. 3-4) classifies the data needed in simulation studies to three categories: Technical data, organizational data and system load data. These categories include lots of the same elements as table 3 in chapter 3.3.

Bangsow (2015, p. 3-4) also presents some required data included in these three categories in table 4**.**

Table 4. *Required data for simulations (Bangsow, 2015, p. 4).*

Technical data	
Factory structural data	Layout Means of production Transport functions Transport routes Areas Restrictions
Manufacturing data	Use time Performance data Capacity
Material flow data	Topology
Accident data	Functional accidents Availability
Organizational data	
Working time organization	Break scheme Shift scheme
Resource allocation	Worker Machines Conveyors
Organization	Strategy Restrictions Incident management
System load data	
Product data	Working plans Bill of materials
Job data	Production orders Transportation orders Volumes Dates

Banks (2004, p. 426) points out that if possible, required data should be gathered from an existing system of interest. Very often it is not possible to gather data from the system or the system does not provide all the necessary data. In these cases, previous knowledge and expert opinions should be used to create best possible guesses and assumptions.

3.3.2 Process modeling

Simple processes can be modelled with flow charts and block diagrams and manual calculation can also be used. More complex systems need to be modelled with different computer based software. Simulation software have different methods on how to construct a model: some have simple blocks, some need more programming etc. But all models have some similar attributes despite the differences how they are presented. These attributes can be divided in to physical elements and logic elements. Physical elements include entities, workstations, resources and storages. Logic elements include processing times, routing and arrivals. Usually when a simulation model is being built, the physical models are usually constructed first and then the logic between them. There are also some properties that are included in the physical elements such as availabilities, buffer capacities etc. (Hwaiyu, 2016).

3.3.3 Problems with simulations

According to Heihala (1999), simulation is not always the best option. There are some disadvantages and cases where simulation should not be used. These are presented in table 5**.**

Table 5. *Advantages and disadvantages of simulation (Heihala, 1999).*

Advantages	Disadvantages
Helps to choose right options Helps to understand why something happens Analyze different options Problem diagnosis Expand understanding Plan visualization change preparation Rational investments Training Requirement specifications	Training requirements Interpreting problems with results Requires lots of resources Can be used wrongly

According to Banks (2004, p. 1-8), simulation has become very extensively used tool in different industrial operations. However, there are several cases where simulation should not be used. Ten rules when simulation should not be used have been listed by Banks and Gibson (1997). These rules are:

1. Common sense can be used
2. Analytical problem solving can be used
3. Real system experimenting can be used
4. Simulation expenses are greater than savings
5. Lack of resources (software, personnel etc.)
6. Time deficiency; not enough time to achieve results from the model
7. Insufficient data in the design phase
8. Lack of model validation and/or verification
9. Expectation can’t be met
10. System is too complex

Simulation is a very good tool but with some disadvantages. The simulation model is a mixture or art and science and building a working and reliable model requires expertise that is gained with time. The results received from simulations can sometimes be hard to translate into practical information because the received data can be a result of plain randomness. Simulation is also very time consuming and usually very expensive (Banks, 2004, p. 5).

4. RESEARCH METHODS AND LITERATURE

The development of the production system through simulation is divided into two parts: literature review and simulation study. To map the theory base of the research, a literature review was done based on the scope of this thesis. The literature review includes existing theory of production system development with different methods and theory of simulation from various sources that was used to create a frame for the simulation study. The simulation study was conducted as a quantitative research because the purpose was to observe numerical data that was used to evaluate the production system.

The gathering of the data happened by being a part of the project group that oversaw designing the new body shop and by conducting interviews with people from different departments. By taking part in the everyday work lots of information was gathered from the target. The interviews were conducted as focused interviews with the people in charge of different departments. A focused interview was a good method for the research because it allows more free discussion and complementary questions. The questions were not targeted to gain quantifiable analysis but more to map various aspects that may affect the research.

Simulation study was used to evaluate the production system because it is cost efficient and the threshold to use simulation is low. The simulation study was conducted with Tecnomatix Plant Simulation program by Siemens.

The methods used in this research were selected because of their usability: the methods had to be cost efficient and not disturbing the ongoing production and project. Information was gathered from the production system that could be used in the building of the simulation study, simulation model and that could be used to evaluate the development proposals. The rest of the research material is gathered from literature.

4.1 Literature review

The theoretical part of this thesis focuses on the development of production system related literature and simulation related literature and articles. Because the empirical part of this thesis was conducted as a simulation study, it was very important to have a good theoretical base for the building phase of the simulation model.

The theoretical part of this thesis focuses also on literature dealing with lean principles because the target company is a contract manufacturer for cars and the production is using lean principles. The purpose of the theory part was to map the principles of lean philosophy that are being used in this type of manufacturing industry to ensure feasible development proposals for the production system.

The most significant books in the development of production systems and lean were *Improving production with lean thinking* by Santos (2006), Hosseini et al's (2015) *Lean manufacturing* in Davim's (2015) *Modern manufacturing engineering,* Izumi's (2015) *Lean manufacturing* in Geng's (2004) *Manufacturing engineering handbook* and Martinsuo & Blomqvist's (2010) *Prosessien mallintaminen osana toiminnan kehittämistä*. These writings were used because the information was considered reliable and the quality was considered good.

In simulation related theory the most significant writings were *Discrete even system simulation* by Banks (2004), *Introduction to modeling and simulation* by Carson (2005), *Tecnomatix plant simulation: modelling and programming by means of examples* by Bangsow (2015) and *Use of simulation in manufacturing and logistics systems planning* by Heilala (1999).

The written literature is gathered from Tampere University of Technology's library and from the library's online material. Some of the source material is available for free as online material. Authenticity of the source material was evaluated to ensure the reliability of the literature review.

4.2 Familiarization with the production system

The familiarization of the production system was an ongoing process throughout the entire study but was more focused in the beginning of the work while gathering material and data. The familiarization happened by taking part in the ongoing project that was planning the production for the new car model. The work included normal tasks such as taking part in meetings, planning process and other smaller tasks. During the familiarization the co-workers were interviewed unofficially to get more familiar with the processes and production system. The purpose of the familiarization was not to improve the production system but to gather data and information from the production system for simulation study purposes. The purpose was to get a clear picture of the target processes and the aspects affecting the whole production system. Information and data was gathered from the production system by observing, interviewing and studying documents.

4.3 Simulation study

Simulation study was used to evaluate the new body shop, because simulation is an effective and reasonably priced method to evaluate a production system and observe problematic areas and development ideas. A simulation study can be executed without disturbing the ongoing production. The simulation project followed mostly Banks' (2004) steps in a simulation study presented in chapter 3.2. During the simulation study the parameters of the simulation model were changed several times resulting in some simulation runs being executed without following Banks' (2004) steps.

The problems, limitations and targets of the simulation study follow mostly the research problems and goals of this thesis but in addition, the simulation study had to include more evaluated issues that were not in the scope of the original research problem. The material flow sufficiency and means to improve it was evaluated with the simulation study.

4.3.1 Acquisition of the plant simulation program

Part of this thesis included the acquisition of a simulation program. This included mapping different stakeholders inside the company to get the idea of the real need for the program license. When the actual license was decided, proper offers for the actual license and education was acquired. A plan for the acquisition and training was made and suggestions for future system development were made to access applicable data easier and more precisely in the future. Siemens has also other Tecnomatix products that can be used in process simulations, material handling, plant design etc. These other products are designed so that they can be used with each other and the data is easily transferrable. However, these other options were not taken into consideration when this program acquisition was made as the acquisition part would have grown into a major part of this thesis.

The simulation program used was Siemens Tecnomatix Plant Simulation. This program was selected because the company had previous simulation models that have been made with the same program. Acquisition of the program allows the modification of the old models inside the company thus making the company's engineering department more self-sufficient. Yours truly had also previous experience from the program which helped in the preparation of the acquisition and in the actual simulation.

Siemens Tecnomatix Plant Simulation is a DES program that is used to simulate, visualize, analyze and optimize logistic systems (Siemens, 2014). The system enables digital model building and allows the user to analyze system's components and parameters thus making it possible to run different scenarios and experiment on different parameters without touching the physical process. The program offers clear and comprehensive data analysis that allows good assessment of different manufacturing plans. The program can be used to simulate entire plants but also smaller lines thus making it possible to optimize material flow, utilization of resources and various levels of logistics. Plant Simulation can be used in everyday operational activities and in the planning phase before any actual system installations are being made. Some key features are:

- Fast modeling with ready object libraries
- Graphical analysis of throughput, resource utilization and bottleneck detection
- Energy analysis
- 3D Visualization
- Support for multiple interfaces (CAD, XML, Oracle SQL etc.)

The program follows the same standards as Microsoft Windows which makes it very easy to use. The model building is fast as the objects can be dragged from the toolbar directly into the working area. There are ready libraries that have components for specific processes, for example automotive processes. The library is also expandable with user's own objects and components. The simple user interface makes it possible to build and manage even complex models (Siemens, 2014). The user interface is presented in figure 12**.**

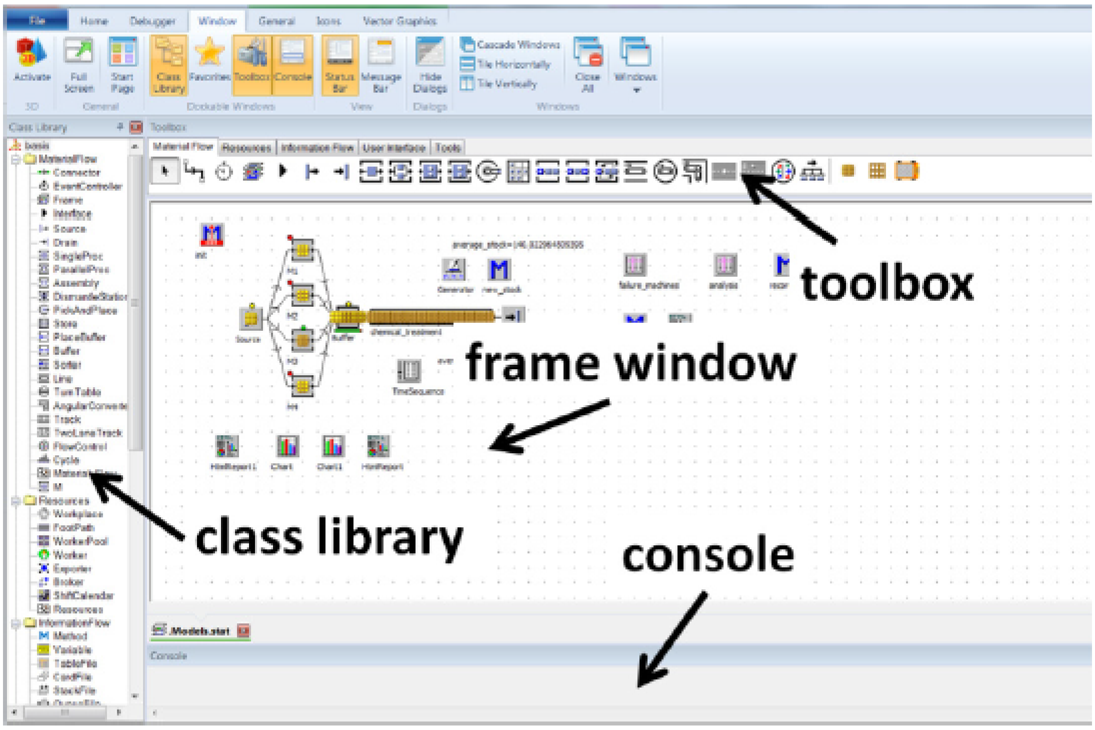


Figure 12. *User Interface of Siemens Tecnomatix Plant Simulation (Bangsow,2015, p. 8).*

Plant simulation's features makes it a versatile tool for different departments in engineering. It can be used to plan and function daily operations in several areas such as internal logistics, external logistics and production planning. The model connects all these areas so that numerous different variations can be simulated and analyzed. Especially in automotive industry that has implemented lean philosophy, uses JIT in part deliveries and where logistics play a key role, it is very useful to use such simulation tool.

During the rough simulation, different program options were mapped. The different license options were received from the same supplier that provided the rough simulation model with some price information. License options are presented in appendix 1. From these different license options, it was clear that the license to be acquired was the professional license as the other license types were not sufficient for the planned use and the research license had options that were not considered useful at this point. The license type was concurrent meaning that the program can be installed to multiple PCs but it can be utilized only by one user at a time.

The license has options for future expansions such as value stream mapping, warehouse logistics and interface package to name a few. These expansions were not considered to be vital at this point of this acquisition so their detailed attributes and prices were not included in the acquisition.

The program was acquired from a company called Ideal PLM. The company is the sole service provider of Siemens products and support in Finland. Siemens does not sell its products directly to customers in Finland. VA also has past and present deals with Ideal PLM and they provided the best price.

Training is a key part when acquiring a new program and taking it into use. Without training the program will be useless and the potential benefit would not be reached. It is very important to have a plan for training so that the program could be taken into use as soon as possible.

The training for the program will be done in two phases. The quotation for the program included two days of training. The content of the training was tailored according to the customer needs because the time was not sufficient to cover the whole program. The first phase of the training included only personnel from the manufacturing engineering department that would use the program in planning the new body shop.

The second phase will be a more detailed training that should include personnel from other departments and the training will concentrate on the needs of all these different departments. This training and its planning with the competitive tendering is not included in this thesis.

4.3.2 Development

With the professional license, it is possible to create own libraries and objects with specific characteristics. This way if there are some stations of other equipment that are big in quantity and are used in various places, it would be easier to create a specific object for that and use the same object for all instead of altering the options and characteristics of each object individually.

These objects can be saved separately so that they are not model specific so they can be used every time there is need to build a new model. The modifications are not restricted to the characteristics but the objects can also be made to look specific meaning that it is possible to import separate 2D and 3D drawings and images. This way it is possible to build a virtual clone of the actual production that is used to visualize processes and can be then used in several ways. For different visualization uses in the future, a 3D plant model is recommended to have. The 3D model of the plant model could be used to present production to different clients, subcontractors or other cooperation partners. There are numerous situations where a visual model could be used.

What needs to be considered with the 3D model though, is that the virtual clone made with plant simulation is not absolute. It is not possible to simulate e.g. specific robot movements and collisions with the program. Plant Simulation is a tool for simulating logistic processes and it should be used as such.

4.3.3 System description and modelling

To increase the effectiveness of present and future simulations, the required data and assumptions should be clearly available for the simulation builder. Because the future simulation models are being built in house, the simulation builder will have increasing knowledge about the factory's processes and this will help in the building process. However, the usable data should be easily accessible and in understandable form to avoid unnecessary time consumption from the simulation builder and other employees.

The processes that require or are wanted to be simulated should be modelled at some level. This means that there should be clear representation of the equipment used, stations, numerical data of the cycle times, availabilities etc. There are several various aspects that can be simulated and the available data should be provided according the simulation targets. Depending on the simulation project, these issues should be discussed in more detail with the customer that ordered the simulation.

4.3.4 Data acquisition

Data acquisition is the most difficult part of a simulation study and most time-consuming part with model building. To execute future simulations easier, the required data should be easily available. Each department concerned by the simulation should have access to specific information. When cross department simulations are concerned, having a databank that is accessible by all stakeholders is important. This databank should include all the applicable data and information and the interested parties who run the simulations should have access to this databank. Because there will be future simulations done in the company, it is very important to have standardized methods for data collection. For future simulation model building to be efficient, processes should be documented and the details should be available for the simulation expert. Depending on the type of simulation, this data should include at least information from table 4 presented in chapter 3.3.1.

Determining the availabilities is the hardest part of data acquisition. There are several ways to measure the availability for each station. One effective way is to gather information from the system and calculate the actual availability based on hours that the machine has been running and the hours it has been down. With these it is possible to calculate the real availability of a stations, cells or manufacturing lines.

Other way is to determine a specific value for each piece of equipment in the stations and calculate the availability based on these values. This method does not provide as accurate values. The availability values for different equipment does not necessarily stay constant as the equipment will wear off with time thus decreasing the availability. This can be held more constant with effective maintenance plan.

In the latter method, it is important to have a clear list of what each station has. Every tool and piece of equipment needs to be listed per station. Tool changing will have effect in the total availability as well. If there is a tool changer and several tools that are not used simultaneously, then the total availability should not include all the tool but only the ones that are in use. This will of course make the availability determinations more complex as it can be hard to determine which tool to use in the total availability determination. There is also the possibility of modeling each tool separately in Plant Simulation. This will of course increase the spent time in model building but will increase the accuracy of the model as it takes into consideration all the possible tools and tool changes with separate availabilities, but in this case the stations need to be modeled in a very detailed way. Depending on the results, the time spent on model building does not necessarily pay off in the results, meaning that sometimes it is better to simulate with more rough availability values and build the model faster and approve the error possibility in the results.

5. CURRENT STATE ANALYSIS AND MATERIAL FLOW SIMULATION OF CAR BODY SHOP

The target company Valmet Automotive (VA) is a contract manufacturer and a service provider for automotive industry. This includes manufacturing, business services and engineering for products and manufacturing systems. The company was founded in 1968 and during its history it has provided services to multiple different customers. The company has headquarters and the main plant in Finland but they also have offices in Poland and Germany. The main plant in Finland manufactures roof systems and whole cars and also provides engineering services.

This study focuses on the main plant's body shop. Currently there are two body welding lines in the body shop, one for each manufactured car model (GLC and A). This chapter focuses more on the body welding process of the Mercedes Benz A-class model, because it is the process under revision.

5.1 Products

The company manufactures products for automotive industry. Currently these products consist of whole cars and roof systems. The strength of the company is the flexibility in the manufacturing process through which the manufactured products can adapt to customer needs and requirements rapidly. Figures 13 and 14 show some of the past and present products.

Figure 13. *Mercedes Benz GLC currently manufactured in VA. (Industry Europe)*

Figure 14. *VA manufactured Porsche during from 1997 to 2011. Porsche Boxster (1997-2010) and Porsche Cayman (2005-2011). (VA homepage)*

The main product of the company is car. The manufacturing process consists of body welding, painting and assembly. The whole manufacturing process is designed to allow simultaneous production of different car models.

Body welding includes welding the body together. Usually each car model receives its own welding process that allows flexibility, efficiency and high quality. VA is currently the leading user of welding robots in Finland and the rate of automation is over 90%.

Painting includes preparation of the body, car bed treatment and painting. The whole painting process is designed to be flexible and it can paint varied materials and car models with assorted colors without being interrupted.

Final assembly consists of multiproduct assembly line reinforced with sub-assembly lines. The assembly is done by hand which allows excellent quality assurance. The final assembly is done according to customer orders and the sub-assemblies and parts from suppliers are integrated with JIT principle.

5.2 Current body welding process

The entire body shop in VA is 24 000 m^2. This is divided between two body welding lines. The body welding line for the A series is approximately 14 000 m^2. The two welding lines are almost entirely separated from each other and they are used to manufacture two different car models. The only phase that is common for each welding line is the finishing that is used for both car models. In finishing the car bodies are finalized and prepared for painting. Before painting both models go through curing oven that is used to harden the adhesive materials.

The body welding process is run almost entirely by automation. Over 90% of the body welding process is automated and only small portion is operated by human labor. The work done by humans consists mostly on part placing in the machines, maintenance work and manual part transportations.

The current process flow is presented in figure 15**.** The blue lines indicate material being transferred via conveyor systems and red lines indicate manual transfer.

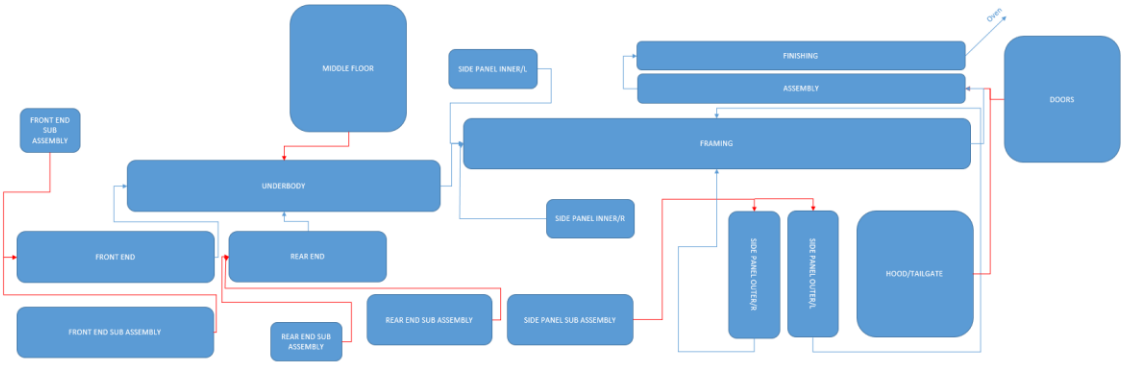


Figure 15. *Process flow of present body shop.*

5.2.1 External logistics

The overall inbound process is simple: material handling department gives a supplier a demand for the parts with exact dates when parts are needed. Supplier produces the parts and books a transportation for them. These bookings are transmitted to transport companies, who will load the parts and will then transport them to VA. After the pick-ups, the transport companies update the license plates of the trailers into the system which allows the material inside them to be traced. When the parts are delivered to VA, they will be unloaded from the trailers and from there internal logistics will handle the material. The traceability helps in the unloading scheduling as the logistics planners know what each trailer holds inside. After the unloading the material is inspected and approved for production.

Incoming parts are transported on various kinds of packages that include metal racks, plastic racks, plastic boxes, wooden framed pallets and cardboard boxes. The body welding process consists of metal parts that are delivered in metal racks. The supplier for the body parts is Daimler and the parts come in circulating metal racks. Outbound logistics also includes the transportation of the empty packaging units back to the supplier.

External logistics include several different logistics related tasks. The whole external logistics team has 30 engineers that are divided into 3 sub departments: packaging, transport and customs and forwarding. Packaging department is responsible for packaging material which includes designing and agreeing packages with the suppliers and empty package transportation back to suppliers. Transport department is responsible for handling daily transportation issues with suppliers. This includes communication with material planning department, suppliers and carriers. Transportation is also in charge of the material unload planning and outbound transport of manufactured cars. Customs and forwarding oversees doing the customs reporting for inbound and outbound material.

5.2.2 Internal logistics

Internal logistics is one of the key areas in VA's daily processes. They are responsible for transporting the correct part numbers to correct production locations on time. Together with material handling, they also keep track of the inventory for several types of parts because they oversee warehouse planning.

Warehouse planning includes part storing and part transfers from all different storage areas. There is storage room in the plant itself but VA also has external warehouses that work as intermediate storages. These external storages are used mostly to store assembly parts but not the body parts that are welded or glued. Body parts are stored in the plant because the gluing process requires that the body parts are within a certain temperature range for the glue to stick properly.

There are many distinct types of parts used in car manufacturing and these parts are divided into 4 sub sections based on their type of warehousing. These 4 types are rack storage, miniload, floor storage and synchro storage. All these distinct types have unique way of storage control and different storing places. There are several ways of storing the material because the inbound logistics might be less costly if some of the suppliers and part numbers are delivered in the same packages due to less empty space in the trailers. Normally there is only one part number per package.

Rack storage is automated warehouse unit and each of the part numbers have their own place. Most of the incoming material is stored in the rack storage. Miniload consists of packages that have part numbers from several different suppliers and several different part numbers from the same supplier. These packages are handled manually and the part numbers are separated from the delivery packages to smaller packages that are used in the internal deliveries. Floor storage is manually operated storage area that has one part number per package. Synchro storage is a storage that has only synchro parts, meaning that they are an assembly of several parts.

The system working model is straight forward. There is usually only one package place in the production that has parts. When the parts are nearly used, the machine or station operator scans a bar code that is in the package. After this the system receives a signal that a specific location needs parts and sends a message to a carrier driver. The system also provides a time frame for the driver during which the full package must be delivered to the working station. The plan is to have the new parts stored as near the place of utilization as possible. When the new package has been delivered, the driver will pick the empty package and deliver it to an intermediate storage for empty packaging. From these storages, the packaging senders produce a daily inventory and based on this they send empty packaging back to suppliers. All inventories are managed with first in, first out (FIFO) principls meaning the first material arriving to storage is the first one to be consumed in manufacturing.

Internal logistics is divided into two sections: operational section and development section. Operational section oversees the daily actions such as inventory amounts and warehouse management. Development section will plan new storage layouts, develop material flow timing (monitoring the punctuality of internal deliveries), external warehouse planning etc.

5.3 Present simulation model

The company has an existing model from the previous body welding process design with also a simulation model from the entire factory's production, including paint shop and general assembly. The model has been previously ordered from an external supplier in 2012. The company has also an updated version of the body shops made in 2016 that has the new GLC body shop included. This updated model does not have the general assembly or paint shop included but only the body shops for both car models and the curing oven.

The 2012 model was used when designing the current body welding process. The first rough version that was ordered for this new project was loosely based on the old existing model.

The previous model was verified and validated when it was designed and back then the simulation model gave reliable results and the results also correlated the actual production volumes. But the model was 5 years old and there have been changes in the actual body welding process so the previous model was outdated and could not be used as such. It was also made with an outdated version and the only available model was an executable version so it was not possible to make any alterations directly into it. Also, the programming language has had an update after the model was built so the model was built with the old programming language version. This would have also caused some confusion in the building process.

The previous simulation model was built on the existing layout with all the sub-sections being in their own frames. This way each separate line could be simulated as standalone experiments with very little work instead of working with the entire body shop every time there is a change somewhere.

The previous model included the entire plant. There was some programming made that concerned the entire model and not just the body shop. Going through the entire program would require time to solve which part of the program concerns only the body shop.

The previous model was not validated by the new supplier but the information in the simulation model was considered reliable and it was decided that the previous simulation model could be used as such as a base in building the new model.

5.4 New body welding process

VA will start to manufacture a new car model in 2018. The production of the current A-class model will stop by the end of the year 2017. The target is to create a new and unique body welding process for the new car model with high reusing rate of the tools that were used in the previous car model. The new welding line will be built to the same location where the current A-model welding line is. This will result in changes in the layout, automation and material flow. To meet the demands of the client, it is very important that the process is sufficient. As a part of the process and layout design, the body welding process is simulated to verify the plans and to achieve the best possible process.

5.4.1 New product

The new car model that will replace the old A-model will be a compact sized personnel car. The new product will have different shape and size and it will also have options that affect the body welding process. All the manufactured products have high quality expectations and the process itself has certain numerical targets that needs to be reached. Also in the plans of the new body shop, it is important to take into consideration other vehicles of the same product family to allow more flexibility in manufacturing.

The new car model will have almost the same processes involved than the previously manufactured model. However, the usage of these processes and the amount of equipment will change greatly for the new model. For example, the amount of spot welds will increase by 581 pcs and clinching will be increased by 55 pcs. MIG- brazing will be added as a completely new process.

5.4.2 New layout

The new welding process requires changes in the layout. The final location of the body welding process will stay in the same place and some of the working stations and working cells will stay in the same places, but there will also be new cells and some major modifications will be made in the older cells which will cause them to grow bigger and be moved from the previous locations.

The body welding process is divided into three sub-sections: Zone 1, 2 and 3. Z1 includes the processes for the front end, rear end, underbody and middle floor with their subassemblies. Z2 has the inner and outer body sides and the bodyline. Z3 has the doors, hood, tailgate and the assembly line. These sections have different processes and by dividing the entire process into sections it is possible to divide the workload. Each of these zones have their own responsible personnel that do the planning for their own sections.

Z1 has the biggest changes in layout. In the entire Z1 area the conveyor systems will be reused but modified for the new parts. The new process for the front end will be built on the existing lines and it will stay quite similar. The subassembly areas will be rebuilt. The subassemblies will have new parts in the structure that require increased robot capacity. The front end does not require special technology and it will consist of reused robots with modifications and new fixtures.

Middle floor is also built on the existing lines. The size of the actual cell will grow and the equipment will be new due to quality requirements and unique part design. This includes welding equipment and fixtures.

Rear end will face substantial changes. The actual space needed will grow by 210m^2. The new line will be built on the existing line but it will require extensions for the actual line and its subassembly line. The increase in space is due to increased amount of equipment; 8 additional robots will be added when compared to the old rear end line. The old rear end robots will be reused in total. Fixtures will be mostly new due to unique part design.

Underbody will be built from the existing line but with new additional station. The new underbody requires increased quantity of robots due to increased amount of parts. The old robots will be reused partially but are mostly renewed due to quality requirements. The old fixtures and grippers will be reused as much as possible and modified to meet the need of new product specifications.

The body sides will be built on the existing lines. The body sides will have unique geometry that requires new fixtures but some of the old fixtures will be used when possible. The body sides will be divided to inner and outer sides as they were in the previous model. The current tools will be reused when possible. The body sides will use adhesive bonding and this will require new gluing pumps and controllers because the change in the adhesive bonding material. The glue dispensers will be reused. The subassemblies for the body side subassemblies will have increased buffer capacity. Almost all the previously used robots for the body sides will be reused with some new robots as well.

The body line will have major alterations. The biggest change in layout is due to difference in the roof beam sequence. The entire process area will be built on the existing line. The fixtures, grippers and welding equipment will be modified and reused. The adhesive bonding material change requires gluing equipment update. The robots will be reused with some additional robots as well.

Closures (door, hood, tailgate) will require more area due to increased quantity of robots and welding equipment. The entire process will be built on the existing line and the floor area is increased by 100m^2. Fixtures will be updated due to unique part geometry and the grippers will be new. The old welding and laser brazing equipment will be reused with modifications. The quantity of robots will increase by 21.

Assembly and finishing will not change much when compared to the old car model. The changes include different screwing method and rearranging stations. Some modifications in the tooling will be made. The fixtures will be new due to unique part geometry. The process area will be built on the existing line.

The overall amount of equipment will be increased greatly. The quantity of robots, stations and guns will be increased greatly but the amount of gluing will be reduced. The hardware will be reused as much as possible and all areas require update in PLCs.

Some of the internal logistics is now handled with manual transportation. Some of this will be replaced with conveyor systems to release man made labor to other sections and to improve the existing manual transportations. The process flow of the new body shop is presented in figure 16**.** The blue lines indicate material being transferred via conveyor systems and red lines indicate manual transfer.

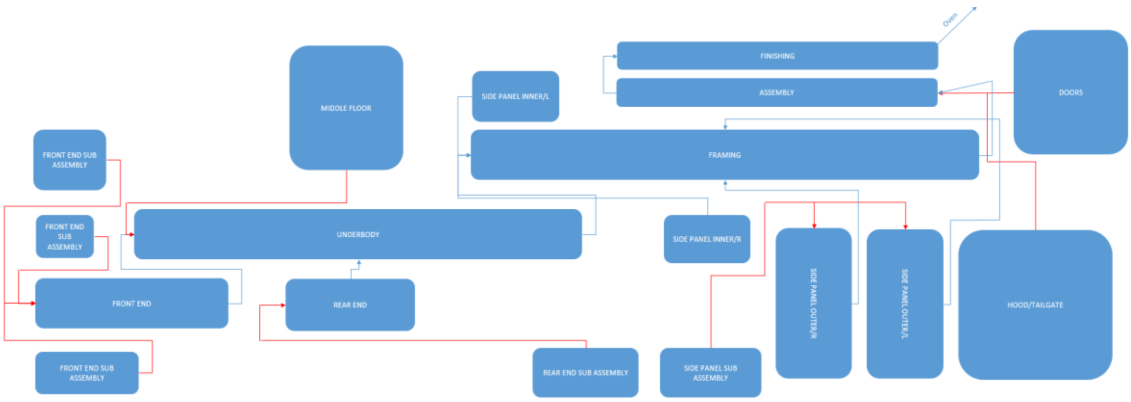


Figure 16. *Process flow of upcoming body shop.*

5.5 Simulating the new body welding process

The new body shop was simulated to ensure the validity of the plans. The simulation was used in the planning phase already so that there was the possibility to make changes to the plans before deadline.

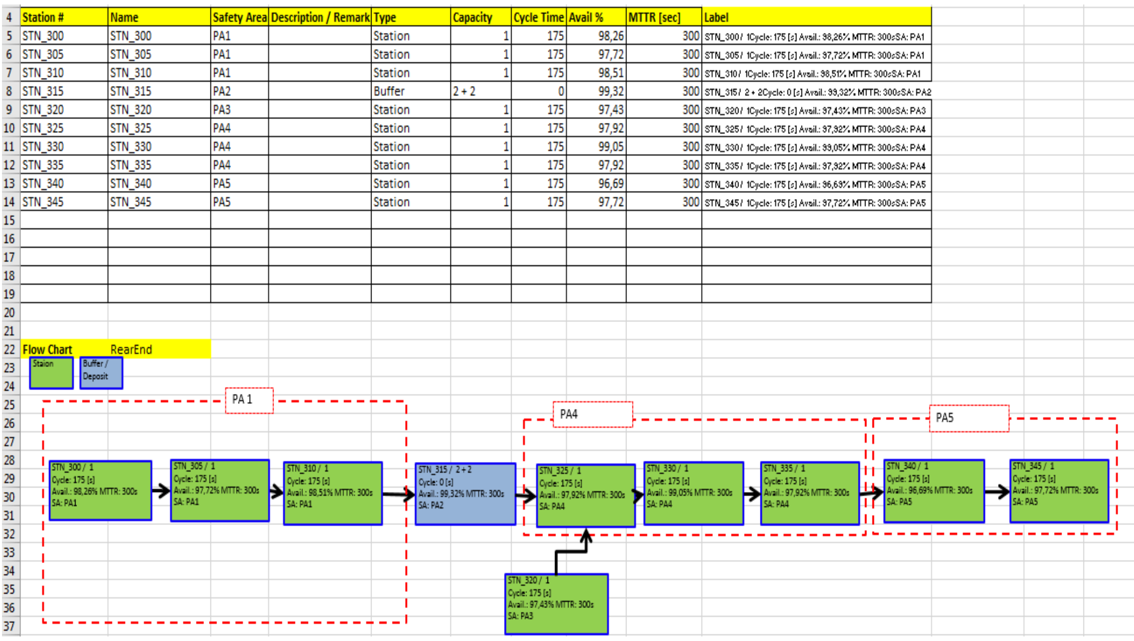
The body welding process was simulated in two phases: first phase was a rough simulation based on the new layout and parameter estimates. The rough simulation was done in an early stage of the plans and its purpose was to determine if the current planning was sufficient and what were the areas of development. The second phase was a fine simulation where the process layout was carefully revised and the parameters used were analyzed carefully. The fine simulation also introduced the manual logistics in the body shop that were not included in the rough simulation.

5.5.1 Rough simulation

The rough simulation model was ordered from an external supplier because there was no simulation program in VA at the time that could have been used for the simulation. The simulation program acquisition was a part of this thesis and the timeframe for the acquisition of the program would have been too tight when the timeframe of the whole project was taken into consideration. The new project plans for the new body welding process had to be done by the end of November.

The rough simulation model was supplied by a German company called PPI-Informatik. The company provides different services for industries, including simulations. The previous simulation model of the current body shop was given to the supplier with updated layout and data from the new body welding process. The original plan was to use the original model and make the changes directly into it, but as the previous model included the whole plant with car models that are not being produced anymore, it was easier to start building an entirely new model that included only the new body shop. Later this model could be used as a base for the fine simulation and future model building.

The rough model was built with information that followed the data collection principles presented in table 4, in chapter 3.3.1. Not all the areas were not deemed necessary such as system load data. The required data for the model was collected for each zone with the help of their responsible planning personnel. The gathered data included layout, station list, material flow between stations and zones, safety areas, buffers, deposits, cycle time per station, availability and Mean-Time-to-Recover (MTTR) per station. MTTR describes the average time that a device or a component needs to be repaired. The data from the entire body shop was collected to an excel file that was delivered to PPI Informatik. Example of the data for one area is presented in figure 17. The rough simulation model is shown in figure 18.



	Station #	Name	Safety Area	Description / Remark	Type	Capacity	Cycle Time	Avail %	MTTR [sec]	Label
5	STN_300	STN_300	PA1		Station	1	175	98,26	300	STN_300 / 1Cycle: 175 [s] Avail.: 98,26% MTTR: 300sSA: PA1
6	STN_305	STN_305	PA1		Station	1	175	97,72	300	STN_305 / 1Cycle: 175 [s] Avail.: 97,72% MTTR: 300sSA: PA1
7	STN_310	STN_310	PA1		Station	1	175	98,51	300	STN_310 / 1Cycle: 175 [s] Avail.: 98,51% MTTR: 300sSA: PA1
8	STN_315	STN_315	PA2		Buffer	2 + 2	0	99,32	300	STN_315 / 2 + 2Cycle: 0 [s] Avail.: 99,32% MTTR: 300sSA: PA2
9	STN_320	STN_320	PA3		Station	1	175	97,43	300	STN_320 / 1Cycle: 175 [s] Avail.: 97,43% MTTR: 300sSA: PA3
10	STN_325	STN_325	PA4		Station	1	175	97,92	300	STN_325 / 1Cycle: 175 [s] Avail.: 97,92% MTTR: 300sSA: PA4
11	STN_330	STN_330	PA4		Station	1	175	99,05	300	STN_330 / 1Cycle: 175 [s] Avail.: 99,05% MTTR: 300sSA: PA4
12	STN_335	STN_335	PA4		Station	1	175	97,92	300	STN_335 / 1Cycle: 175 [s] Avail.: 97,92% MTTR: 300sSA: PA4
13	STN_340	STN_340	PA5		Station	1	175	96,69	300	STN_340 / 1Cycle: 175 [s] Avail.: 96,69% MTTR: 300sSA: PA5
14	STN_345	STN_345	PA5		Station	1	175	97,72	300	STN_345 / 1Cycle: 175 [s] Avail.: 97,72% MTTR: 300sSA: PA5

Figure 17. *Example of one section in the excel file containing the data.*

In the top part of the figure is presented a station list and their attributes: safety area, station type, capacity (both station and buffer capacity, value in amount of parts), cycle time, availability and MTTR. In the bottom part is presented the material flow in that specific area in a simple block diagram. The safety areas are marked with a red colored dashed line.

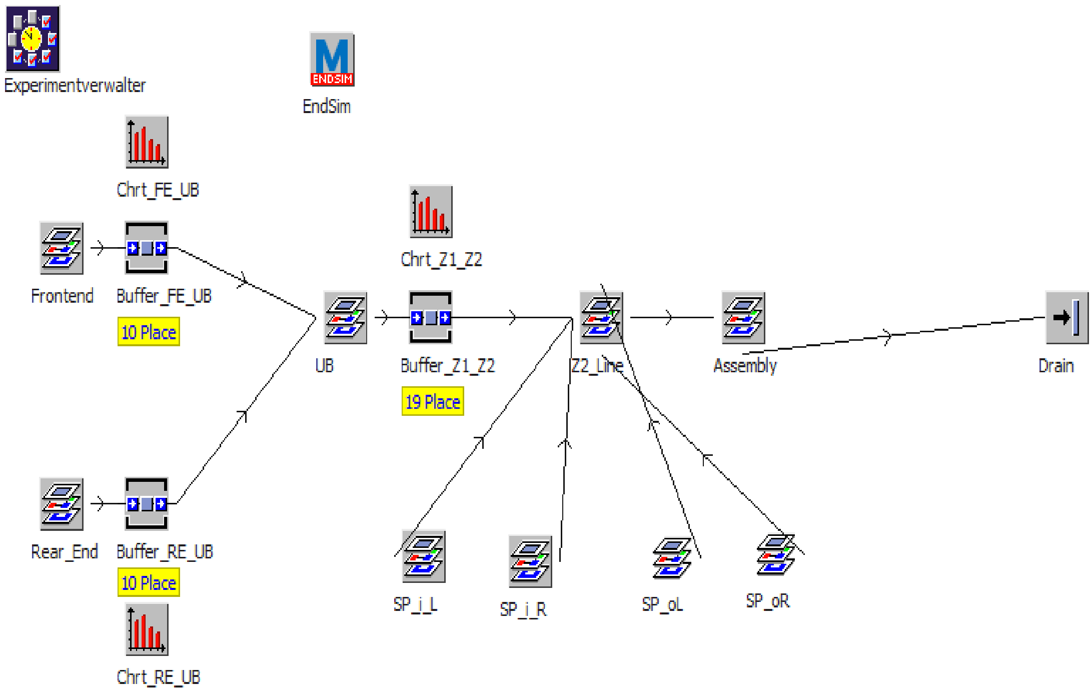


Figure 18. *The rough simulation model of the body shop.*

The data acquisition was considered difficult. It was hard to determine exact values because the timeframe was very short and there were no databanks or properly detailed history for the required values. Because the simulation study was for a new body shop, there were no possibility to collect usable data from an existing system. More detailed data acquisition would have required a lot more time than was available. This is also the reason why the simulation was done in two steps.

The rough simulation was done with constant values for the cycle times and MTTR. For the availability, it was not possible to determine a constant value because there are several types of stations and conveyors that work in a very different way and have distinctive parts that influence the total availability. Most of the data had to be collected through the area planners and even with their help the data was hard to acquire.

The availability values were hard to gather. There were no decent tables that would indicate the availability values for the robots or their tools or other system specifications. Therefore, the availability values were estimated by using a table that was received from the supplier of the rough simulation model. The table had some availability values for some specific robots and other equipment that was had been used by an OEM car manufacturer. The availability values were estimated by using this table, but there were several tools that were not in the list and therefore educated guesses had to be made. In these situations, the availability values were rounded downwards because otherwise the results from the simulations might have been too optimistic. It was not possible to use the same availability values from the previous simulation model, because there were no specific values per tool, but only total availability values for a specific station that included several pieces of equipment.

MTTR values were set for 5 minutes because the same value was used in the previous simulation model for the previous car model. The same MTTR value was used in all the stations despite their availability values.

The cycle time for each station was set for the target value. Only differences in the cycle times were in the finishing line because the manufactured car models go through a common finishing line and there the cycle time is faster than in the new body shop. The other car model produced has the same cycle time with the finishing line. Also, the door, hood and tailgate areas of the new car model have different cycle times.

The body shop was examined separately as sub sections and as whole. This was done to determine if the sub sections met the target values and if the total body line would meet the target values. This way it would be easier to locate the bottlenecks. In the rough simulation, the finishing line was not simulated because there are two car models going through the same finishing line so there was no point of simulating it with only one model as those results would not be feasible. The results from the total body shop does not consider the finishing line at all. The combined effect of both models was studied in more detail during the fine simulation.

The results were compared with the project target values. The technical capacity was multiplied with the target total availability to receive the capacity that needs to be met. For each of the standalone experiments and the total body line experiment, a 55-day simulation was used. This length was considered sufficient as the deviation in the results after 55 days was considered small enough. In this 55 days, the first 5 days were the warmup days during which the stations and buffers were filled. The statistics were measured during the next 50 days. This was done to get more accurate results from the actual production as the start of the production would not give realistic results from the continuous production. The whole production was working in two shifts and 5 days per week. Efficient working time per shift was 460 minutes. The results received were an average of 20 runs to get reliable values. KPI's for the total body shop were availability and jobs per hour (JpH). Jobs per hour means how many parts are finished within one hour and can be used to indicate the performance of a single station or in this case the total body shop. The results from the standalone experiments and for the complete body shop are shown in figures 19 and 20.

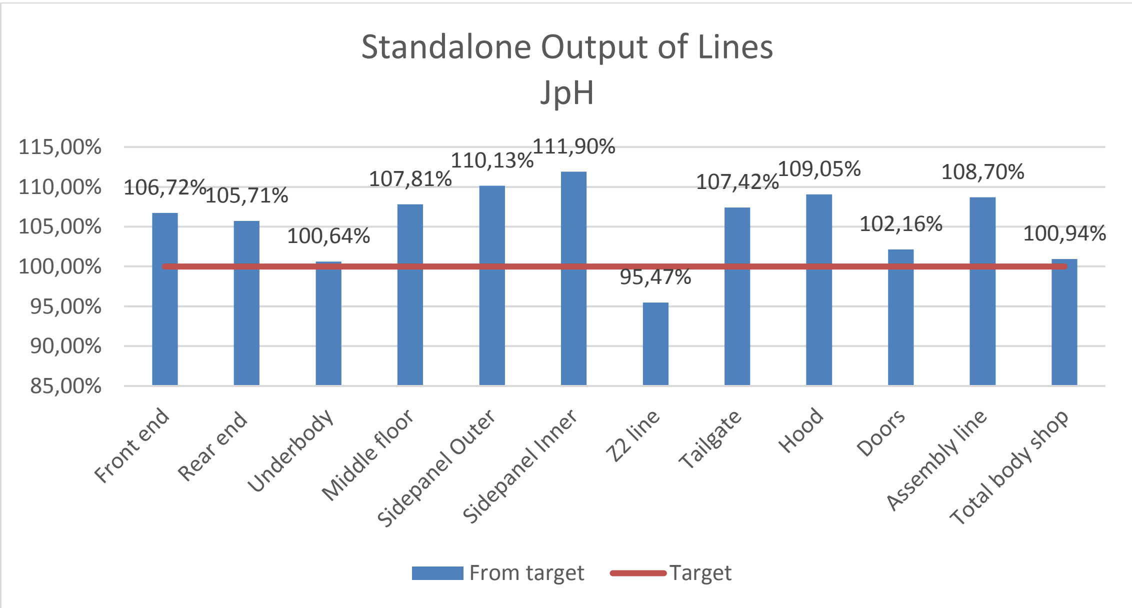


Figure 19. *Standalone results for JpH from rough simulation.*

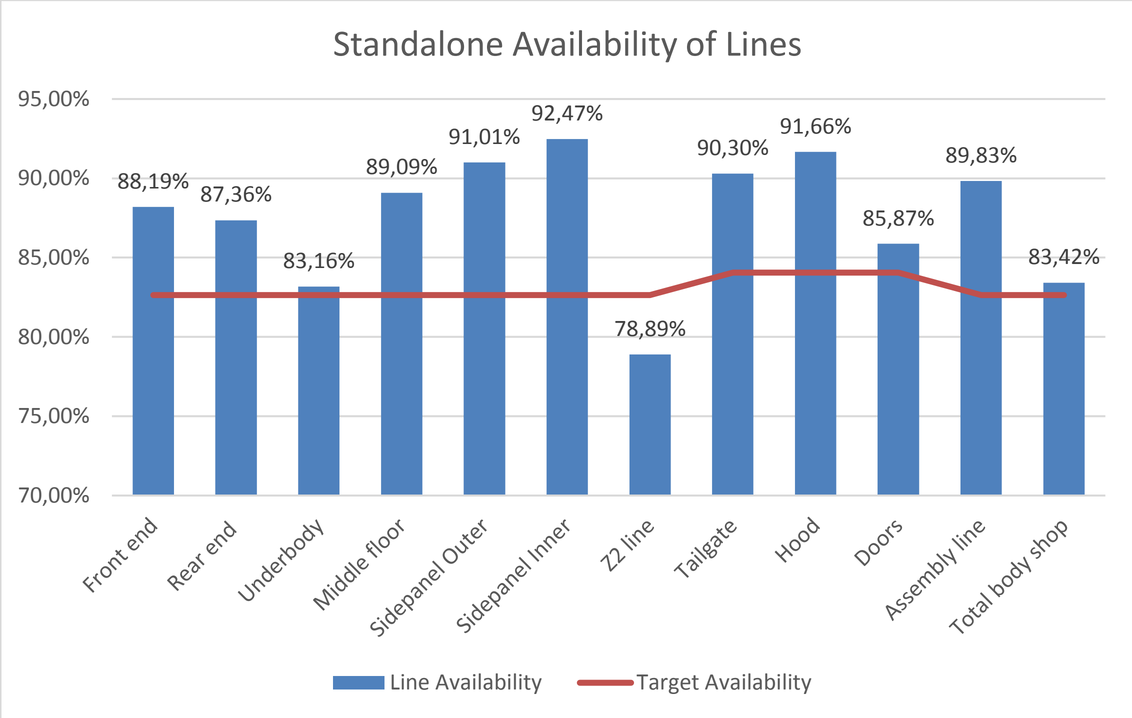


Figure 20. *Standalone availability results from rough simulation.*

If the standalone values of each subsection are observed, then all the results do not meet the target values. As figure 19 shows, the standalone result for Z2 line is below the target value by 4,53%. But even if the Z2 line is below the target value, the total body shop will reach the target value. This is because front end, rear end, underbody, middle floor and body sides are run constantly through the brakes. This will affect in filling the buffers for assembly line that will eventually decouple the negative effect of Z2 line.

The availability values for the body shop by area are almost in every case above target. The only exception is Z2 line that is below target with 78,89%. This happens because the Z2 line is the biggest line with the most stations and tools. However, the total availability of the entire body line is 83,4%. This is below the target value of 85%. The reason why the JpH results are above target with below target availability values is because the real gross JpH for all the lines is more than the JpH used in calculations.

These results give good insight to the total performance of the body shop plans. However, this rough simulation should be considered with certain reservations. The model does not include manual transportations between working stations and so the decoupling effect between areas such as doors, hood, tailgate and middle floor is unknown. These sub sections that had manual transportation to other lines were not included in the availability calculations which might affect in the total availability as a reducing factor that may influence the total production. What also must be considered, is that the availability values added in the simulation model are not absolute as they were mostly educated guesses with guiding values and thus they may be different from the correct values.

5.5.2 Fine simulation

The rough simulation model was made in German language. If it would be used as such for all future simulation then it would not be an issue, but for the fine simulation it was difficult, because all the building blocks were in German. The first thing in the fine simulation was replicating the rough model into a new model that would be in English. This was done by copying the model block by block. In this phase, the model was also modified for easier and quicker handling. These modifications included adding automatic calculations at the end of the simulation so that there was no need for manual calculations based on the reports. A more universal working time determination was added so the working time for every area could be determined with one block instead of determining it separately for each area. Before experimenting, the English version of the simulation model was verified so that the results were the same with the German simulation model to ensure the similarity between the two models.

In the rough simulation, the areas that were manually delivered to the body line were considered always available. In the fine simulation, these manual transportations were modelled to ensure accurate results, because the failures in the areas that had manual transportations were not included in the overall availability thus big failures in these areas might have influence in the overall production volumes.

The fine simulation included the final layout plan so there was no more changes. However, the final layout had the same arrangements in the stations and in the areas, so this did not cause any changes in the fine simulation. The availabilities were reviewed for the fine simulation. This was done by checking the final tooling lists for each station and comparing the lists with the ones provided for the rough simulation. This resulted in similar values so the availabilities for the stations were kept the same. One critical change was reviewing the failure modes throughout the model. In the rough simulation, the failure modes differed between stations and areas. In some stations, the failure mode was set for the entire simulation time, in some stations it was set for operating time and in some stations, it was set for processing time. The state of failure mode will have significant effects in the results as the in the simulation time failure mode the failure might happen even if the machine is idle. In operating time, the failure can happen during the setup time or the processing time and processing time failure mode can fail only during the processing time. The failure mode for all the stations were set to operating time because the equipped tools cannot fail unless they are used.

The cycle time for the stations were also kept the same. The background of the fine simulation model was the logistics pathways layout and the building blocks included AutoCAD files from their representative areas. This way the simulation model could be scaled to real dimensions and the distances between stations and areas would be accurate. This would also help in explaining the model to others than just the model builder. The fine simulation model is presented in figure 21.

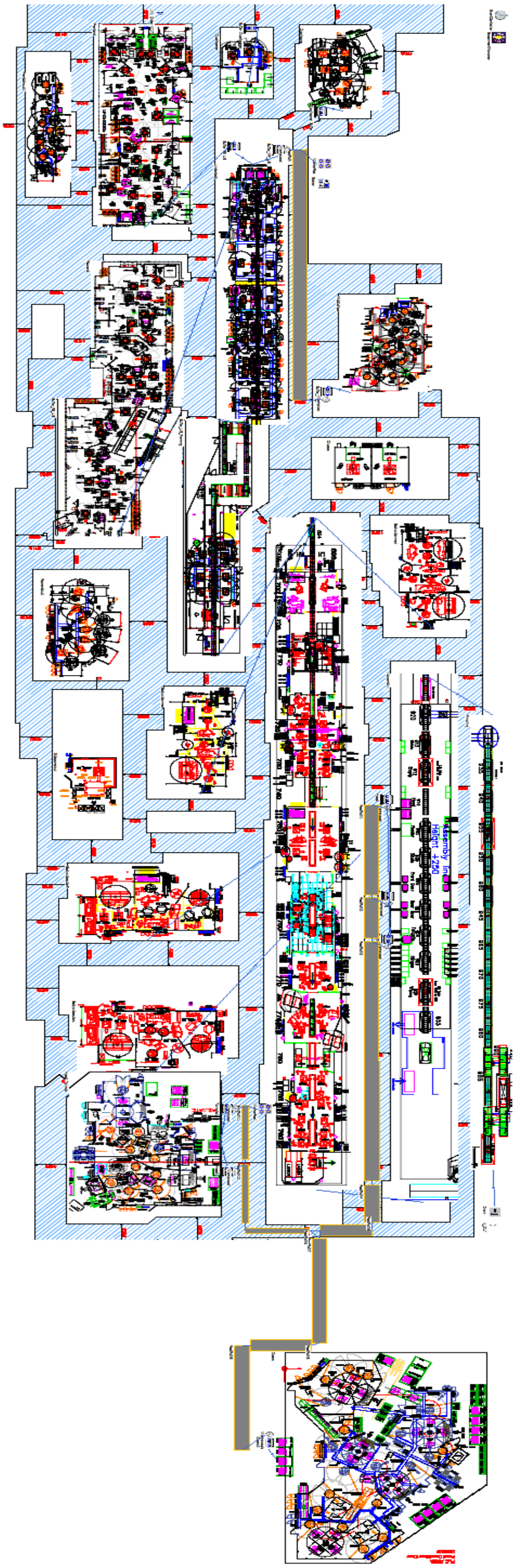


Figure 21. *The fine simulation model.*

After the fine simulation model was finalized, the experimenting was done again. The experiment was conducted the same way as the rough simulation; areas were studied first as standalone areas and then the body shop was studied as a complete unit. The experiment time was kept the same, 5 days with a 5-day statistic reset. The results were an average of 20 experiments and the working time was two shifts per day, 5 days per week. The results are shown in figure 22 and 23.

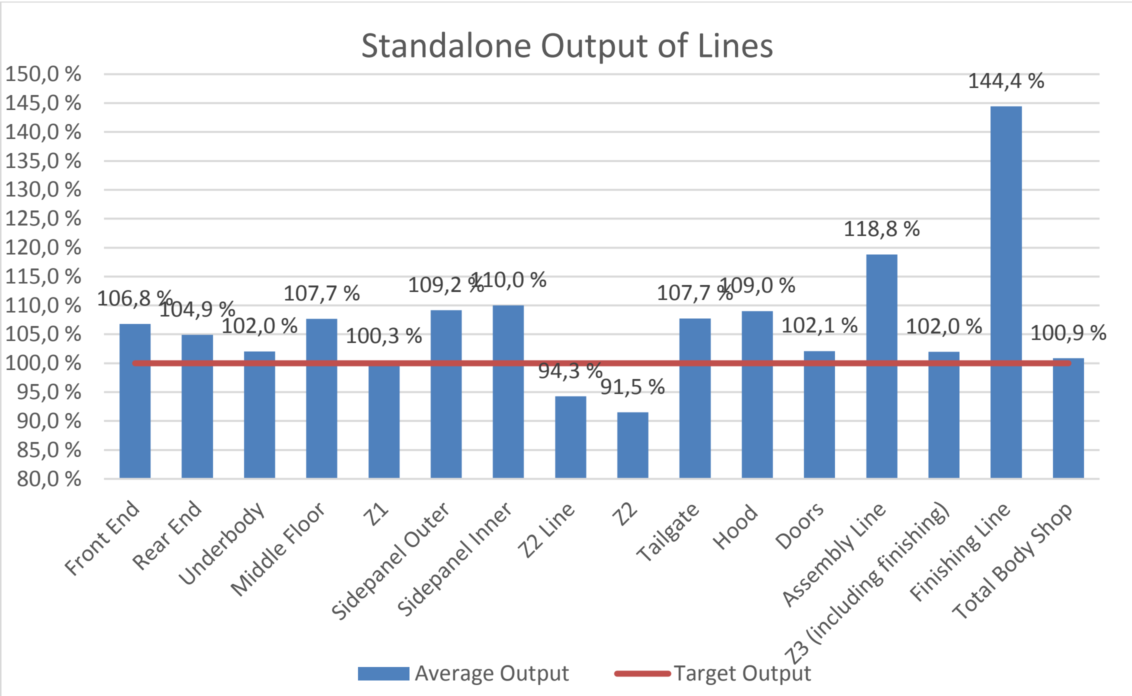


Figure 22. *Standalone output of lines.*

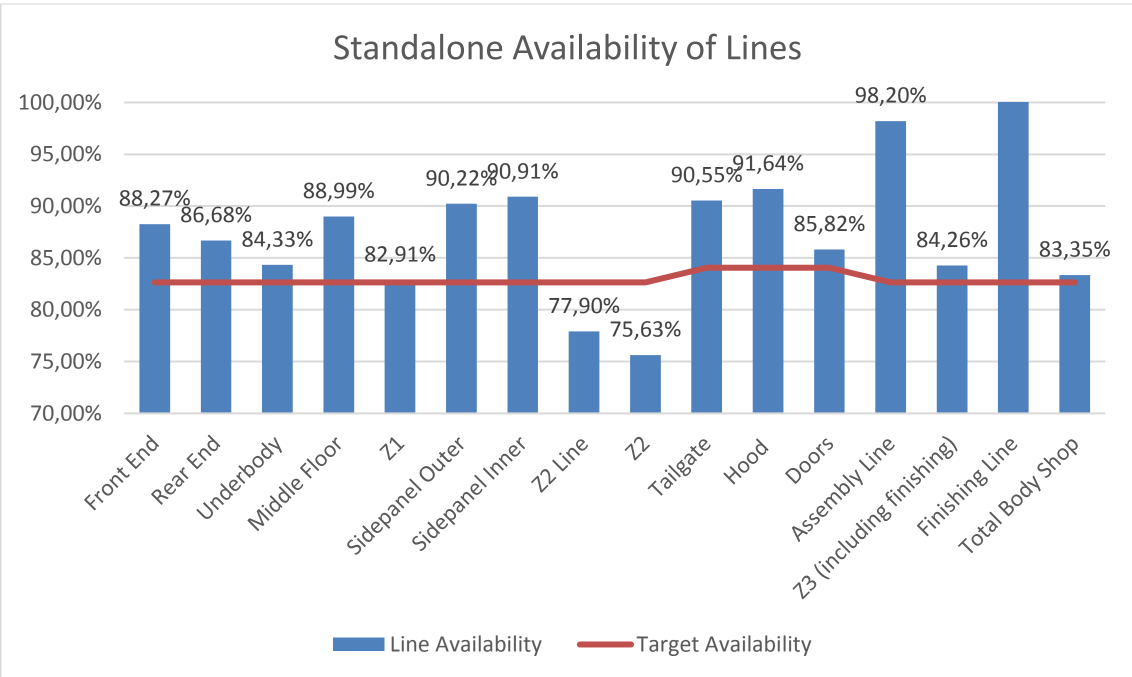


Figure 23. *Standalone availability of lines.*

The results show that the fine simulation provided comparable results with rough simulation. Each of the lines are above the target values except Z2 line and the Z2 area. But the buffer between Z2 area and Z3 area and the different working time model between these areas decouple the output of Z2 area. The total output of the total body shop with the finishing line is just above the target with 0,9 %. The total availability is still below target of 85% with 83,35%.

5.5.3 Combination of two car models

After the fine simulation was conducted, additional experimenting was done by adding the second car model into the simulation model. This was done, because the two car models that are manufactured have their own body shops, but they share the same finishing line. The other model also has different cycle time than the new car model will have. This combination of different cycle times will affect the total output of the finishing line and the total output of the new car model.

The production was planned so that the two car models would be manufactured with different working shifts for each model to ensure the sufficient production volumes. The experimenting was done with different combination of plausible shift models. The abbreviation used to represent the shift models is TAM and it stands for “työaikamalli” in Finnish and translates directly as working time model. The first number indicates working shifts per day and the latter one working days per week. For example, TAM35 means 3 shifts per day and 5 days per week. In TAM25 and TAM26 the working shift is 8,5 hours long and it includes one lunch break of 30 minutes and two coffee breaks of 10 minutes each. TAM35 and TAM36 models have 8-hour shifts including lunch break of 20 minutes with two coffee breaks of 10 minutes each. The used shift models were:

- TAM25
- TAM26
- TAM35
- TAM36

The experiment was conducted with similar experiment methods as the rough simulation and fine simulation. The base for the simulation model was the rough simulation model as it was deemed to provide reliable results. The other body shop was simulated by adding the body shop as a single block with applicable availability and cycle time values. Between this and the finishing line a buffer was added with applicable buffer places and availability value. This was agreed to be accurate enough to simulate the total production of the other body shop.

The peak volume for the total amount of cars in the year 2018 is 480 Jobs per day (JpD). JpD is a similar measurement than JpH, but the time frame is a working day, not depending on the number of shifts. This amount is divided for product 1 260 JpD and for product

2 220 JpD. These were the target values that the results were compared with. The results for the experimenting with both car models are shown in figure 24**.** In the figure, the first TAM stands for product 1 and the TAM after dash line stands for product 2.

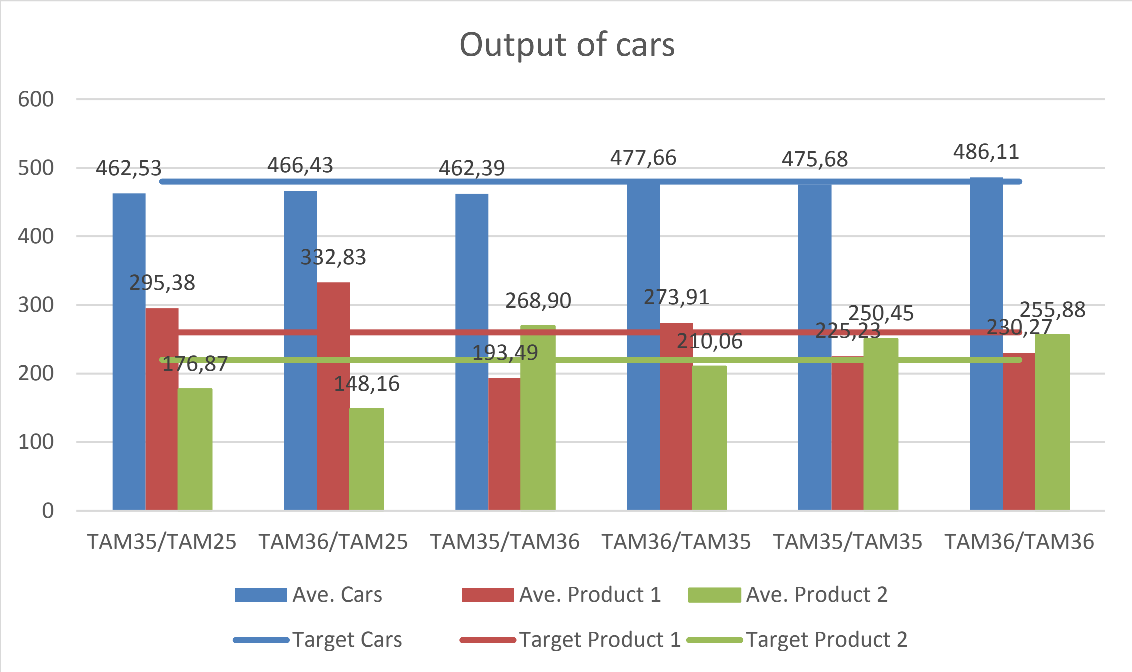


Figure 24. *Results from total output for both car models.*

The results show that none of the combinations of different working time models resulted in a desirable outcome. With only one TAM combination the target for total output was reached: TAM36 for both car models. But even if the total volume was reached the volumes were not divided correctly between the car models. For product 1 the total output was 230,27 JpD and for product 2 the output was 255,88 JpD. This means that the target for product 2 is reached but the output for product 1 is far from the target. This lead to further experimenting with solutions to achieve the target.

TAM36/TAM25 and product 2 buffer changes and cycle time decrease

The target was to manufacture the cars so that product 1 would run in TAM36 and product 2 would run in TAM25 model. The finishing line would work in TAM36. This working model combination was used and the combination of both car models was simulated by changing buffers sizes and changing the processing time per model on the finishing line. The processing time for product 2 was set to 80 seconds and for product 1 it was set for 144 seconds. The buffer size between product 2 body shop and the finishing line was simulated with buffers sizes 0, 17, 70 and 100. The results are shown in figure 25**.**

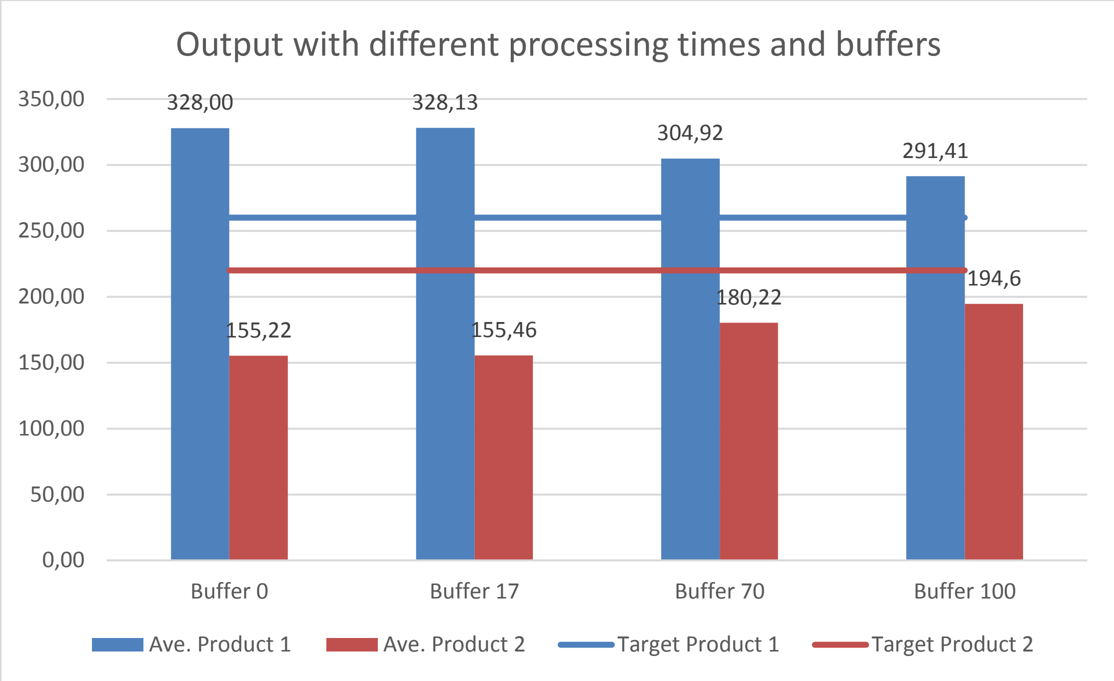


Figure 25. *Output with different processing times and buffers.*

The results show that changing the processing time for product 2 did not change the output of product 2. This is because the body line of product 2 is slower than the finishing line. By increasing the buffer for product 2 before the finishing line, the output is increased. However, the buffer size needs to be very big to reach the target value for product 2. Even the tested 70 and 100 buffer places were not realistic but was used to demonstrate needed buffer size.

Working shift options and change in product 1 buffer size

The option of different TAM models between the two models was also simulated with changes in product 1 buffer before the finishing line. The TAM and buffer combinations simulated were TAM25 for product 1 and TAM36 for product 2 with product 1 buffer of 22 and 39, and TAM35 for both models and product 1 buffer size of 39. The cycle time for both models in the finishing line was 144 seconds. The results are shown in figure 26.

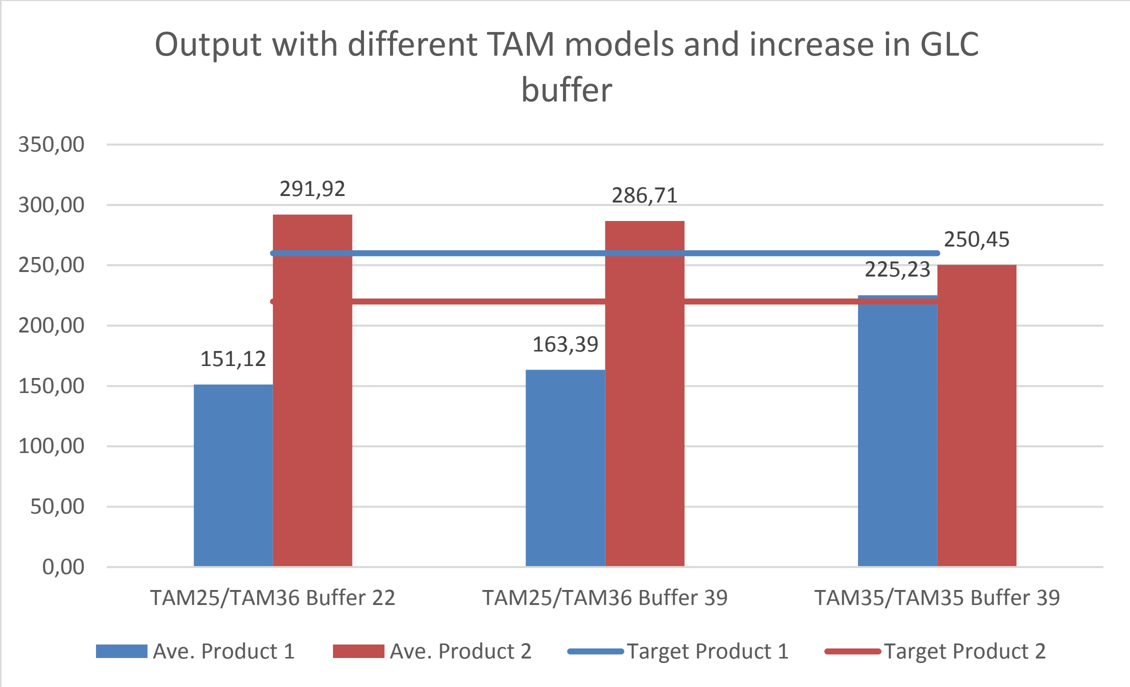


Figure 26. *Output with different TAM models and increase in GLC buffer.*

The increase in product 1 buffer does not increase the quantity of cars per day significantly. Even if the output in two shifts for product 1 would be sufficient alone, product 2 will slow down the combined flow in the finishing line. The third shift per day for product 2 will increase the output of product 2 above the desired level with the TAM25/TAM36 model.

When both car models are in TAM35 model and product 1 buffer was increased to 39 places, the output was close to the target. Product 2 was above the target value but product 1 did not reach the target and was left roughly 35 cars per day behind the target.

2 finishing lines

Based on previous simulations, it was clear that the finishing line worked as the bottle neck before curing oven and painting. This lead to simulating the possibility of separate finishing lines for both car models. This led to the bottleneck moving to the oven, as both car models would go through the oven. Product 2 does not need curing oven due to different adhesives but the possibility of another way for product 2 into the paint shop was considered not to be possible.

A concept of new finishing line for product 1 was made by the members of the project team. The old finishing line was kept as it was for product 2. The cycle time for product 2's finishing line was 144 seconds and for product 1's finishing line the cycle time was also 144 seconds. The oven was also taken into the simulation as its throughput effected the total output of both car models. The model for the oven was updated by the same company that provided the rough simulation model. The TAM models were TAM36 for product 1 and TAM25 for product 2. The experiment methods were kept the same as before. Buffers were added after both finishing lines before the oven and the experimenting was conducted by altering the capacities of these buffers. A mixed buffer was experimented alone and with model specific buffers. The simulation models are presented in figures 27, 28 and 29. The results are presented in figures 30**,** 31 and 32**.**

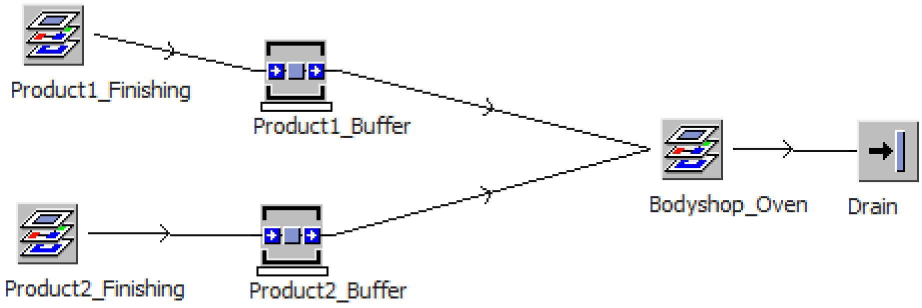


Figure 27. *Simulation model with model specific buffers.*

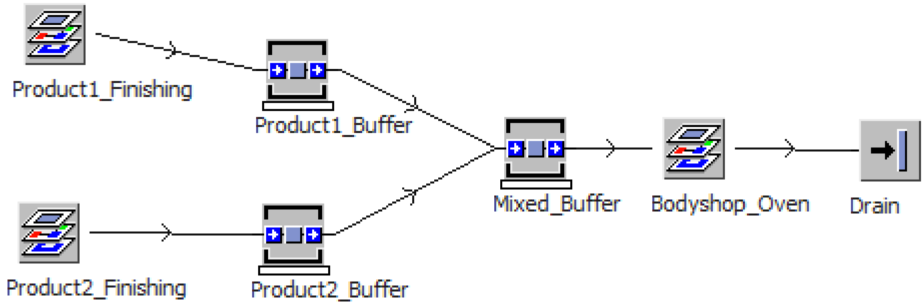


Figure 28. *Simulation model of model specific and mixed buffers.*

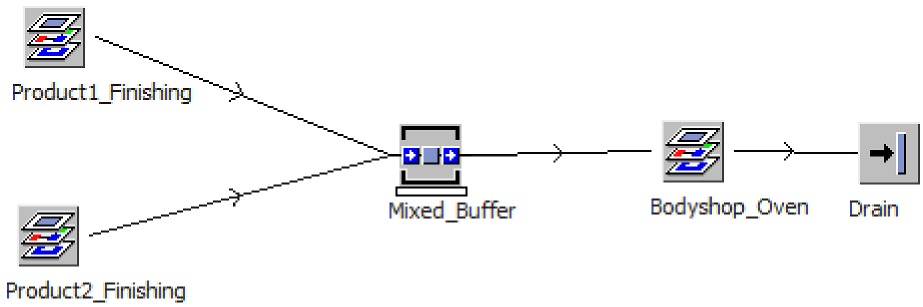


Figure 29. *Simulation model of a mixed buffer.*

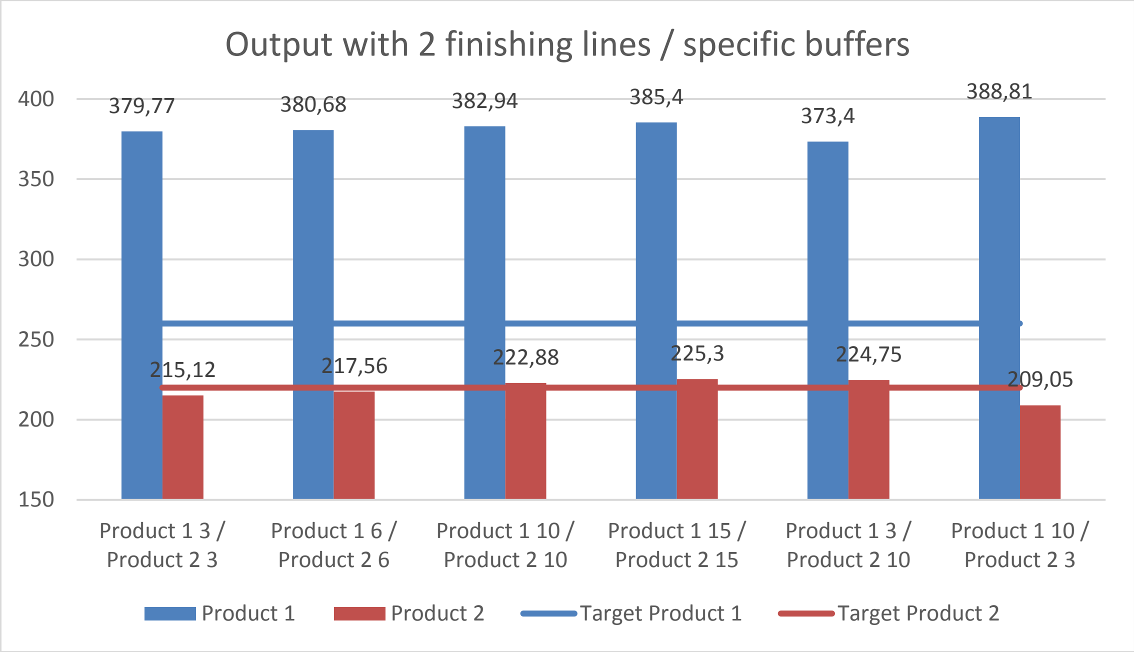


Figure 30. *Output with 2 finishing lines and model specific buffers.*

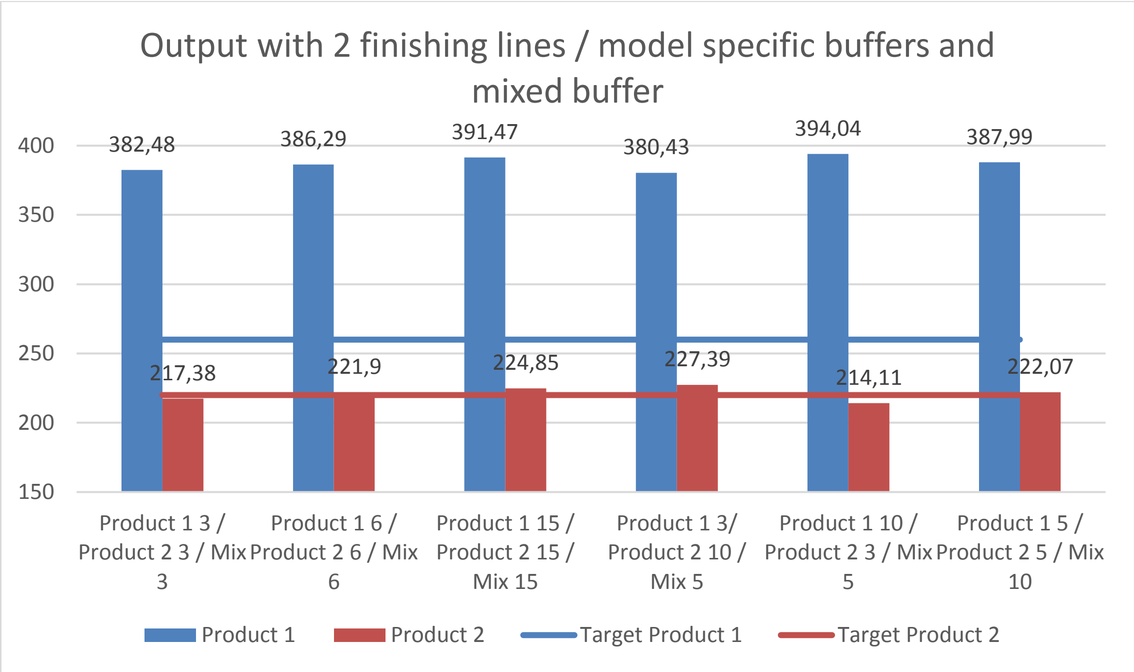


Figure 31. *Output with 2 finishing lines and model specific buffer and mixed buffer.*

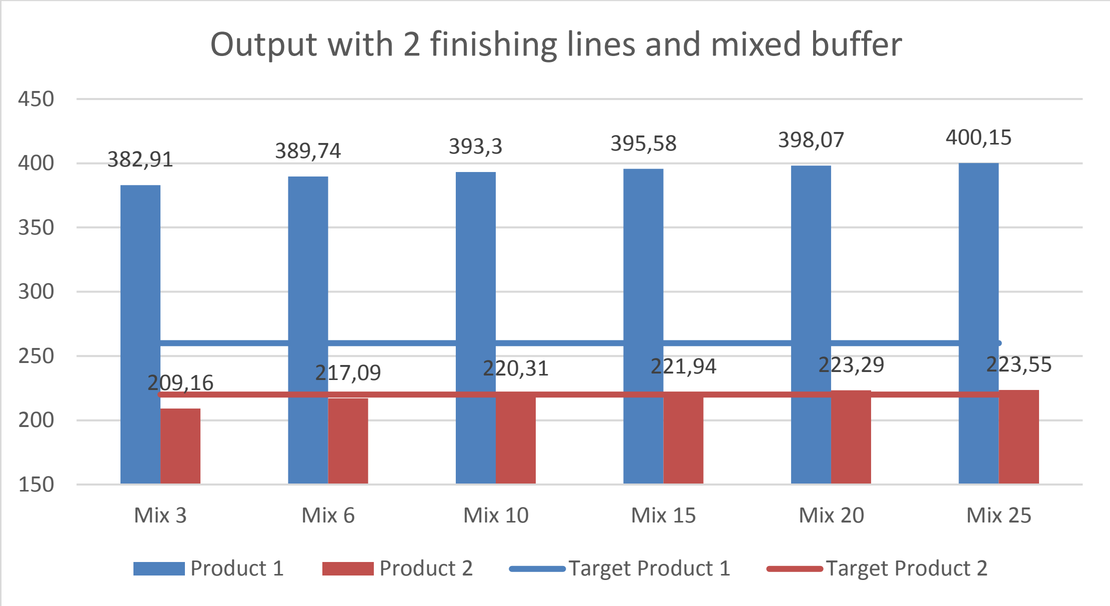


Figure 32. *Output with 2 finishing lines and mixed buffer.*

There were several buffer combinations that resulted in reaching the target values. With every experiment, it was clear that the target for product 1 would be reached without problems. This happens because the body shop for product 1 has a faster cycle time and it is produced in three shifts per day and during the night shift product 1 is the only model utilizing the curing oven thus removing the bottleneck from there.

Product 2 has a slower cycle time and with the other car model utilizing the curing oven, it was clear that the body shop for product 2 could not function with full capacity. The buffer between the finishing line and the curing oven needs to be big enough so that the body shop can run efficiently and when the curing oven has space, there would always be a car body waiting for access. The results show that the targets are reached with different buffer combinations and capacities. The best results were achieved with a combination of model specific buffers and a mixed buffer with product 1 buffer having 3 places and product 2 having 10 places and the mixed buffer having 5 places. This resulted in 227,39 JpD on average for product 2. With the least buffer places, the target was reached with a mixed buffer of 10 places and without model specific buffers. In every simulation, it was clear that product 2 needs buffer before the curing oven to maximize the output of the body shop. The buffer for product 1 should not be too big, otherwise it will start consuming the output of product 2.

6. RESULTS

Table 6 shows that with only one finishing line the desired outcome is below target even if the TAM models and buffer sizes were changed. In some scenarios the targets were very close but in the long run (if observing annual production volumes for example) the below target values will increase costs because of working overtime. The best scenario with common finishing line was achieved with TAM models TAM36 for product 1 and TAM35 for product 2. In this scenario product 2 was below target by 4,52% and product 1 was 5,35% above target.

Table 6. *Results from simulation studies with common finishing line.*

NEW BODYSHOP STANDALONE				
OUTPUT (JpH)		TARGET (JpH)		TARGET (%)
17,16		17		0,94
Combination of both models, common finishing line				
COMBINATION (Product 1 / Product 2)	Product 1 (JpD)	Product 2 (JpD)	Product 1 FROM TARGET (%)	Product 2 FROM TARGET (%)
TAM35/TAM25	295,38	176,87	13,61 %	-19,60 %
TAM36/TAM25	332,83	148,16	28,01 %	-32,65 %
TAM35/TAM36	193,49	268,9	-25,58 %	22,23 %
TAM36/TAM35	273,91	210,06	5,35 %	-4,52 %
TAM35/TAM35	225,23	250,45	-13,37 %	13,84 %
TAM36/TAM36	230,27	255,88	-11,43 %	16,31 %
Different Working shift options, product 1 buffer increase				
TAM25/TAM36 buffer 22	151,12	291,92	-41,88 %	32,69 %
TAM25/TAM36 buffer 39	163,39	286,71	-37,16 %	30,32 %
TAM35/TAM35 Buffer 39	225,23	250,45	-13,37 %	13,84 %
Product 1 TAM36/ Product 2 TAM25, added product 2 buffer, decrease product 2 cycle time				
Buffer 0	328	155,22	26,15 %	-29,45 %
Buffer 17	328,13	155,46	26,20 %	-29,34 %
Buffer 70	304,92	180,22	17,28 %	-18,08 %
Buffer 100	291,41	194,3	12,08 %	-11,68 %

The results from two finishing lines are positive. The target values for both car models are reached with several buffer options as can be seen in table 7. The results show that product 1 is well above the target value and product 2 is also above the target value though only barely. The best results for product 1 are reached when there is a mixed buffer of 25 places. With this setting the product 1 is 53,90 % above target and product 2 is 1,61 % above target. The best results for product 2 are reached with a combination of 3 buffer places for product 1, 10 buffer places for product 2 and a mixed buffer with 5 places. With these settings the product 1 is 46,32 % above target and product 2 is 3,36 % above target. The results show that for product 2, buffer places are needed but even with a reasonable amount of buffer places the target can be reached.

Table 7. *Results from simulation studies with 2 finishing lines.*

2 Finishing lines, model specific buffer				
Product 1 Buffer/Product 2 Buffer	**Product 1**	**Product 2**	**Product 1 from target**	**Product 2 from target**
3/3	379,77	215,12	46,07 %	-2,22 %
6/6	380,68	217,56	46,42 %	-1,11 %
10/10	382,94	222,88	47,28 %	1,31 %
15/15	385,4	225,3	48,23 %	2,41 %
3/10	373,4	224,75	43,62 %	2,16 %
10/3	388,81	209,05	49,54 %	-4,98 %
2 finishing lines, model specific and common buffer				
Product 1 Buffer /Product 2 Buffer /Mixed Buffer	**Product 1**	**Product 2**	**Product 1 from target**	**Product 2 from target**
3/3/3	382,48	217,38	47,11 %	-1,19 %
6/6/6	386,29	221,9	48,57 %	0,86 %
15/15/15	391,47	224,85	50,57 %	2,20 %
3/10/5	380,43	227,39	46,32 %	3,36 %
10/3/5	394,04	214,11	51,55 %	-2,68 %
5/5/10	387,99	222,07	49,23 %	0,94 %
2 finishing lines, common buffer				
MIX	**Product 1**	**Product 2**	**Product 1 from target**	**Product 2 from target**
3	382,91	209,16	47,27 %	-4,93 %
6	389,74	217,09	49,90 %	-1,32 %
10	393,3	220,31	51,27 %	0,14 %
15	395,58	221,94	52,15 %	0,88 %
20	398,07	223,29	53,10 %	1,50 %
25	400,15	223,55	53,90 %	1,61 %

7. DISCUSSION

The results from the simulation study were both positive and negative. During the study, some development areas were found and solutions were found for these areas based on the simulations. These solutions required big investments, but the study showed that to reach the targets, these investments are necessary.

Lots of information and hands-on experience was also received from simulations. Simulation in general was considered to have positive gain when designing production systems, but performing a simulation study was deemed challenging. The whole study would have been faster to conduct if there would have more previous experience from simulations.

The targets of the simulation study were partially achieved. The plans for the new body shop were verified with great promise, but the combination of two body shops did not produce desired results at first. The common finishing line for both car models was observed to function as a bottleneck with the desired working time models thus resulting in negative output for the new body shop. A solution for this was discovered by simulating different scenarios. By investing on another finishing line, the bottleneck was removed from the common finishing line resulting in desirable results.

The simulation study gave lots of information about the production system and about simulation studies in general and previous experiences from simulation studies have been positive. The results from these studies have correlated the results received from real production. To improve future simulation studies, the collection of data and information should be started in an early phase to ensure correct model building from the beginning. Experience from this simulation study shows that earlier start gives more time in the actual building of the model but also gives more information about the current state of the planning.

Plant simulation focused more in simulating the overall material flow of the new body shop. In the future, more information can be achieved from the production system by modeling also smaller lines and individual cells with more detailed equipment. The building of more detailed cells and equipment will require time, but the current simulation model can be updated slowly cell by cell after the production starts. This is also something that should be done to build a valid simulation model that can be used in the future to simulate more detailed changes and can also be verified when the production in the new body shop is running. It is also faster to perform simulation studies with an updated simulation model.

Because the plan in the future is to perform simulations in house, necessary actions should be made to ensure efficient simulations. Lots of focus should be appointed towards the data collection and data availability. The acquisition of data from various sources without standardized methods will require time and the variations between users may appear in the reliability of the data. The required information should be easily accessible and in easily understandable form. During the simulation study, the most difficult area of information was availabilities. This area should be improved by creating a possibility to gather real time data of the uptimes and downtimes of each station. During the study, this would have saved time and the simulation model would have been more accurate.

The performer of the simulation should be involved in the projects that include simulations so that he/she would have good understanding of the circumstances. The simulation tool should be used in the future and other departments could be trained to use the program so that it does not rely on one person. This way other departments can also simulate scenarios and gather information related to their department. One option is, that manufacturing engineering would keep the model up to date and other departments would have access to this model. Other option is that all the needed simulation studies are performed in manufacturing engineering department and the simulations for other departments are ordered from this department.

8. CONCLUSIONS

A production system should always be examined as a complete system. Some improvements can result in better functionality but does not necessarily improve the complete system. This was observed also during the simulation study when the cycle time of the new car model was decreased in the finishing line but the body line was remained untouched.

The goals of the thesis were completed in most parts. The plans for the new body shop were verified successfully with the simulation model. The results received from the study showed that the body line alone will reach the target values, but when combining two car models in the simulation model, a bottleneck was observed at the common finishing line. Feasible solutions were found with the simulation model to remove the bottleneck. By investing in another finishing line, the bottleneck can be removed thus resulting in achieving the target volumes for both car models. This means that the simulation study was completed as expected.

To improve the whole production system, investments should be made on another finishing line with applicable buffers. For future simulations, the system should be developed so that needed information can be gathered easily and with great reliability. Simulations should be considered as a tool in different planning, but in mind that even with modern software the results are not absolute, but still very accurate.

During the thesis, lots of information was gathered from the production system. The used methods were recorded sufficiently so they can be used in the future.

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